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**AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS**

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NOTES ON THE GLENN FORMATION OF OKLAHOMA
WITH CONSIDERATION OF NEW
PALEONTOLOGIC EVIDENCE¹

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From the time of the original definition in 1903, little was published which added to our knowledge of the character and relations of the Glenn formation, until 1922, when there appeared the admirable paper by Goldston entitled "Differentiation and Structure of the Glenn Formation."² Attracted by the problems both scientific and economic unfolded in Mr. Goldston's report, and desiring to add to our general knowledge, we spent several days during the past summer examining the section and collecting fossils in the Ardmore quadrangle. That we believe we can add something of value after so brief a visit, to a subject to which others have given so much study, may at first seem rather presumptuous, but thanks to the carefully drawn geologic map of Goldston the time that we did spend was multiplied in results, and furthermore the new facts which we offer are largely on the paleontologic side, in which Mr. Goldston's report appears to us distinctly deficient, and in which should be reckoned not only the time employed in collecting near Ardmore, but also the time employed in making and studying the collections used for comparison. We accept Mr.

¹ Published with the permission of the Director of the U.S. Geological Survey.

² W. L. Goldston, Jr., *Am. Assn. Petroleum Geol. Bull.*, Vol. VI, No. 1, 1922, pp. 5-23.

Goldston's mapping with nothing but praise; we believe that his recognition of the limits of the formation and his correlation of some of its parts are not correct. It seems to us, in the first place, that the base of the Glenn as recognized by Goldston is taken too low and the top too high in the section according to the language used by Taff. Indeed, the total thickness of the Glenn according to Goldston (19,000 feet) is so great as to make the name of little use for practical purposes.

The Glenn formation was originally described and defined in the Tishomingo folio, where the author¹ says:

This formation includes strata of shale and sandstone from the top of the Caney shale upward and may include the highest Carboniferous rocks exposed in the Tishomingo quadrangle. . . . The town of Glenn, from which the formation gets its name is located on the formation in the Ardmore quadrangle.

From this passage it was evidently the author's intention that the typical Glenn should include those rocks that are exposed at and in the vicinity of the small town of Glenn, Oklahoma, and that overlie the Caney shale, the top of the latter formation being the base of the former. On the other hand, it is also evident that he did not intend to include in the Glenn the highest Pennsylvanian rocks of the Ardmore quadrangle (those exposed south of Ardmore itself) for at the end of the discussion of the Franks conglomerate he says:

Limestone conglomerates occur *above* the Glenn on the south side of the Arbuckle uplift in the Ardmore quadrangle interstratified with shales, sandstones, and limestones. Just what part of the conglomerate-bearing beds in the Ardmore region is represented by the Franks conglomerate cannot be determined at present.

The town of Glenn, according to Goldston's map, rests on rocks, belonging to his Deese, Cup-coral, and Otterville members. This small area is surrounded on all sides by a band representing his underlying Springer member. The higher beds are repeated southward toward Ardmore, near which his Hoxbar, the highest member of the Glenn according to Goldston, makes its appearance. It seems to us probable that the Hoxbar member of Goldston represents in a general way the beds referred to by Taff as occurring

¹ Taff, Joseph A., *U. S. Geol. Survey Folio No. 98* (1903), p. 5.

above the Glenn and as possibly representing part of the Franks conglomerate. At all events, the distribution of these rocks with reference to the hamlet of Glenn, taken in connection with the statement quoted from Taff, would indicate pretty clearly that Goldston's Hoxbar was not a part of the Glenn as originally defined. This fact, of course, should not prevent the Glenn from being redefined so as to include those beds, but no evidence, justifying such redefinition is known to us.

We also think that we have substantial evidence for excluding from the Glenn Goldston's Otterville member and everything below it, and for limiting the formation to his Deese and Cup-coral members. Attention has already been directed to the fact that according to the original definition no rocks that represent the Caney shale were intentionally included in the Glenn formation. The Caney shale is typically exposed in the valley of Caney Creek in the Antlers quadrangle. The geology of that area, however, has never been published, and the name was first introduced in the *U.S. Geological Survey Folio No. 74*, the Coalgate quadrangle, 1901. The description is very meager, indicating that its position is subjacent to the Wapanucka limestone and that only its upper part is exposed in this region. During the next two years, folios Nos. 79 (Atoka quadrangle) and 98 (Tishomingo quadrangle) were published, in both of which Taff describes briefly the Caney shale.

The upper limit of the Caney shale in those areas is the lower limit of the Wapanucka limestone, whose typical exposures are in the Atoka quadrangle, which is immediately adjacent to the Antlers quadrangle on the west. Thus the rocks of both formations may for present purposes be regarded as having representative exposures in the Atoka quadrangle. Now Taff did not recognize the Wapanucka limestone in the Tishomingo quadrangle, nor has it been recognized in the Ardmore quadrangle, but instead the Caney shale is immediately followed by the Glenn formation. In the absence of the Wapanucka limestone the upper limit of the Caney shale and, ipso facto, the lower limit of the Glenn are more or less problematical.

This boundary was apparently determined by Goldston on the following evidence. "The basal shales of the Glenn," he says on page 7 of his paper, "are black but much softer in character. A few Pennsylvanian cephalopods were found in the Santa Fe railroad cut north of Berwyn in a sandstone occurring about 400 feet above the base of the Glenn." Referring again to what is evidently the same occurrence, he writes "Charles Schuchert, while visiting the area, was inclined to place the fossil-bearing sandstone near the base of the Springer as the equivalent of the Wapanucka limestone." Bearing in mind that the Wapanucka limestone lies above the Caney shale and forms its upper boundary where both formations are present, and also that by definition the Glenn also is post-Caney, we see at once why Goldston drew the boundary between the Glenn and Caney where he did.

We made a point of visiting the cut near Berwyn, and we obtained a collection of cephalopods there, from the same bed, we feel sure, that was mentioned in the two passages just quoted. Just what ground Schuchert can have had for correlating this bed with the Wapanucka limestone it is hard to see. The fossils that we were able to collect are without doubt cephalopods, but most of them are too ill preserved to indicate clearly whether they belong to the nautiloid or to the ammonoid division. Their general appearance and traces of a few sutures, however, suggest that they are actually ammonoids, but we believe that it would be highly incautious to draw any conclusions from such material. It is possible, of course, that Mr. Goldston may have obtained better specimens, but it seems doubtful that any could have come from this locality in which even the generic characters were adequately shown. Furthermore, ammonoids are especially characteristic of the Caney fauna but are conspicuously rare in the Wapanucka fauna, so that this evidence, so far as it goes, would tend to place this sandstone not in the Wapanucka limestone but in the Caney shale. But there appears to be much more conclusive evidence tending in the same direction.

We have over 50 collections from the Wapanucka limestone and subjacent shale at various localities in the Atoka, McAlester, and Tushkahoma quadrangles, and, as one might expect, they show a variety of facies. To one of these collections especially we

would call attention at this point. The typical exposures of the Wapanucka limestone, as has already been noted, are in the vicinity of Wapanucka in the Atoka quadrangle. About 4 miles northwest of Wapanucka (a mile southeast of Bromide) Delaware Creek has cut through a ridge of this limestone. In the escarpment thus formed the lower part of the more massive Wapanucka consists of a great bed of oolite, about 150 feet thick. This is overlain by cherty limestone and this in turn by sandy limestone. Below the oolite comes a thick series of yellowish-olive to brownish-gray shales. Some thin bands or stringers of limestone, orange to yellowish-gray in color, occur about 50 feet below the top of this shale and from these we obtained a good collection of fossils (Station 4046A).

A section very similar to this is described in the Atoka folio as occurring at a point a few miles to the northeast of our locality, and there can be little doubt that the horizon at which we collected was considered by Taff to belong in the lower part of the Wapanucka limestone and to be above the Caney shale. This lower fauna has a rather conspicuous and peculiar facies. It differs widely from one collected at the same locality in the main limestone above, though this difference may to some extent be discounted by the fact that the higher fauna occurs in beds of oolitic texture. This lower fauna is, however, closely allied to faunas described as coming from the Wapanucka limestone in the Tushkahoma and McAlester quadrangles, and it is strikingly similar to and practically identical with some faunas from a greenish shale in the McAlester quadrangle that Taff regarded as belonging in the upper part of the Caney. Finally this same peculiar and distinctive fauna reappears in the Otterville limestone of Goldston in the Ardmore quadrangle. Such are the facts; the inferences to which they lead are not so clear. It should be understood at once that the fauna of the Caney shale that is at present known is that of the basal beds. It has a Mississippian facies and is totally different from the fauna of the upper Caney, here mentioned for the first time, which has a Pennsylvanian facies.

One interpretation of the paleontologic data just sketched, in so far as the McAlester quadrangle is concerned, is that certain shaly beds which occur below the assumed base of the Wapanucka

limestone and which were included in the Caney, really belong to the Wapanucka. Another interpretation is that the upper Caney forms a distinct unit to which belong certain beds that have locally been included in the Wapanucka, for we find that most of the collections from this formation that closely resemble those of the upper Caney are labeled as from the lower limestone of the Wapanucka. A third interpretation is that no change is needed in the classification of the beds and that the upper Caney fauna merely shows close relationship with that of the lower Wapanucka. The three striking agreements, however, are those between the upper Caney of the McAlester quadrangle, the thin limestone beds that occur in greenish shale below the main limestone of the Wapanucka near Bromide in the Atoka quadrangle (though there classed as part of the Wapanucka limestone itself) and the Otterville limestone of Goldston in the Ardmore quadrangle.

The interpretation of the paleontologic data in the McAlester quadrangle has an important bearing on the classification of the Glenn formation. Whether Goldston's Otterville is regarded as representing in a general way the upper Caney or the Wapanucka, makes little difference in one respect. If it represents the upper Caney, the Wapanucka, is probably absent and we must take the base of the Glenn at the base of the "Cup-coral member," provided we adhere to the original definition in the item of excluding from the Glenn any representative of the Caney. If Goldston's Otterville is regarded as representing the Wapanucka, the result is much the same, for though the former would have to be regarded as Glenn, of the two alternatives of revising the name or abandoning it, revision would doubtless be the more desirable. A third course, and perhaps the best, would be to change Glenn from a formation to a group name, though in doing so one would have to consider the application of the term in the Tishomingo folio where it was first used. Relying upon the extremely close relationship of the faunas found in the upper Caney of the McAlester quadrangle, in thin limestone stringers which occur below the main limestone of the Wapanucka but are nevertheless classed as of that formation, near Bromide, and in the Otterville limestone of Goldston in the

Ardmore quadrangle, we are disposed to regard all three zones as representing essentially the same horizon and to classify them for the present as upper Caney, though we feel that if the facts are as they appear to be, the part of the Caney which is of Pennsylvanian age will subsequently be distinguished from the lower part, which we believe to be of Mississippian age.

The facts which have been adduced seem to go far in showing that Goldston included in the Glenn considerably more than Taff included in it, so that the upper boundary of the authentic Glenn should be taken as the top of Goldston's Deese member, and the bottom of the Glenn as the bottom of his Cup-coral member, or at all events not lower than the bottom of his Otterville limestone. By a strict application of Taff's definition, therefore, the Glenn should consist of only Goldston's Deese and Cup-coral members and possibly his Otterville limestone.

If his Otterville limestone represents a horizon near the base of or just below the Wapanucka limestone (whichever interpretation appears best to comport with the facts) the consideration is pertinent whether all or most of the Wapanucka cannot be found represented in the "Cup-coral member." According to Goldston this series of beds comprises 1,500 to 1,800 feet of blue shale separated by thin sandstones and an occasional limestone with a white limestone near the top containing the characteristic coral *Campophyllum torquium*.

Our collections from this topmost limestone of the "Cup-coral member" show a fauna not only very different from that of the Wapanucka limestone but in our judgment distinctly younger. Another collection from an undetermined horizon in the same member (though possibly also this topmost limestone) does no better, and Goldston's lists agree generally with ours. These facts do not shut out the possibility that the Wapanucka may be represented in some of the lower beds of the "Cup-coral member," if, as seems not improbable, all the paleontologic evidence known came from the upper part. Mr. Sidney Powers in a personal communication has given us assurance that the "Cup-coral bed" (apparently the one forming the top of the "Cup-coral member") is the same as the "Cup-coral bed" that occurs 15 feet below the

top of the Boggy shale. The same assignment is suggested by Goldston's correlation table.

Although the rather individual fauna found in Goldston's Otterville limestone seems to be repeated so closely in beds that have been classed as lower Wapanucka in the Atoka quadrangle and upper Caney in the McAlester quadrangle, thus seeming to establish the correlation of his Otterville on a fairly solid basis and to suggest a restriction of the Wapanucka in its typical area, some evidence that seems contradictory to this correlation cannot be ignored. Limestones and, one might almost say, consequently fossils, are very scarce in Goldston's Springer member in the typical region north of Ardmore. In fact, we were unsuccessful in obtaining any paleontologic evidence whatever from those beds in that region. South of Ardmore, however, his Springer appears to undergo a marked transformation, beds of limestone are not uncommon and fossils are abundant. Regarding this Goldston says:¹

North of Ardmore this formation [Goldston's Springer member] has no calcareous members. There are twelve brownish or drab sandstones ranging from a few feet to over one hundred feet in thickness. . . . Around the Criner Hills, sandstones are less important and numerous beds of thin brownish limestone occur in these deposits.

We were not able to examine all of the Springer member as mapped south of Ardmore, nor did we have time to trace any of the beds examined for any considerable distance. Three good collections, however, were made from the "Springer" in this area. One near the eastern center of the eastern edge of sec. 5, T. 5 S., R. 1 E. (Station 4061), and two along the eastern edge of sec. 2, T. 6 S., R. 1 E. about a quarter of a mile apart (Stations 4064 and 4065).

Two of these faunas were collected at nearby points and are in close mutual agreement: the third (4061) was collected at a different locality and presents a different facies. The fauna of these two collections differs conspicuously from any of the faunas that we obtained in the Ardmore quadrangle and from any of those listed by Goldston. This fact might be taken as for, rather than as against, their derivation from his Springer member, which is paleontologically a blank, were it not that this fauna presents a

¹ *Idem*, p. 7.

facies much younger than his Otterville, and indeed possibly younger than any other yet known in the quadrangle. The latter part of this statement is made with much less confidence than the former, for at least we do not see how a fauna like this could possibly have come from his typical Springer and consequently be older than his Otterville. Therefore, we believe that the rocks at this locality (4064 and 4065) are not his typical Springer, but much younger.

The fauna found at Station 4061 is less varied, less individual, and less certainly identified. At this locality the rock is practically made up of fossils, but most of them are fragmentary and others break up or exfoliate as they are collected so that it is exceedingly difficult to obtain identifiable specimens. This fauna may be of the same geologic age as the other though it is different and less sharply characterized, but at all events it is of a type that almost equally with the other would be paradoxical to find below Goldston's Otterville limestone. Although no statement is appended to the very meager faunas listed by Goldston from his Springer, they consist of nearly the same species that we found. We interpret them in the same way and we believe that they must have been collected from the Criner Hills region (except the goniatite, which presumably is the one mentioned as occurring in the Berwyn cut). However, although we believe that some of the beds mapped as Springer in the Criner Hills are considerably younger than his true Springer, a part clearly represents the Springer member as it is mapped to the north of Ardmore. At one locality north of Overbrook, a dark fissile shale with small concretions and stringers of clay ironstone has all the characters of the middle part of the lower half of the black typical Caney. No serious effort was made by us to delimit the post-Glenn and the pre-Glenn parts of the Springer member as it was mapped in this region.

So many horizons in the thick Carboniferous section about Ardmore are paleontologically unknown that any statement about them is more than ordinarily subject to correction by new evidence. With this proviso clearly understood, we venture the opinion that these younger Carboniferous beds (represented by lots 4064 and 4065, and possibly 4061) are younger than Goldston's Deese and possibly younger even than his Hoxbar. We know almost nothing

of the paleontology of the latter, but the few species cited from it by Goldston do not indicate any material change from the fauna in his Deese. Our own collections from it are negligible. The younger beds of which we speak are apparently in contact with the Springer in some localities and in others with beds of pre-Carboniferous age. Our own explanation of this phenomenon is that of unconformity, but we are far from being able to bring forward any convincing evidence for this explanation as against some other.

At all events, it will be well to bear in mind this occurrence of probable post-Glenn Pennsylvanian deposits at the north and south ends of the Criner Hills, when considering the areas to the west covered by Permian and Tertiary deposits.

As to the probable thickness of the post-Glenn Pennsylvanian, however, we would not even hazard a guess at the present time. It is possible, and somewhat probable, that these higher beds, rather than the Glenn formation, will be found at the base of the Permian in wells. It also is possible, perhaps probable, that wells drilled west of the Criner Hills will find the Glenn formation either thinning or absent due to overlap or unconformity. Well cuttings might aid in ascertaining the facts if properly collected and carefully examined for micro-fossils.

To sum up, we are satisfied that Goldston's Otterville limestone correlates with beds that have been included in some places with the Wapanucka limestone and in other places with the upper part of the Caney shale, but that would probably better be distinguished from both formations though this course would require a redefinition of the Caney. Consequently we are satisfied that the beds which subsequently were comprised in his typical Springer were excluded from the Glenn formation in its original definition, and that they are part of the Caney shale. We are also convinced that it was not the intention of Taff to include in the Glenn the beds which Goldston calls the Hoxbar member, so that the typical Glenn should be reduced to his Deese and "Cup-coral members" with his Otterville limestone at the base, if we accept the Wapanucka limestone as it was delimited in the Atoka quadrangle, which is its typical area. We also believe that in the Criner Hills Goldston mapped as Springer not only beds that correspond to his true

Springer but beds that were much younger, possibly younger even than his Hoxbar member.

Whether the apparent juxtaposition of these beds to his true Springer is due to unconformity or to faulting or to some other cause, we do not presume to say, but our preference at present is to account for it by unconformity. The paleontological evidence that we collected in the Ardmore quadrangle is represented by the following lists.

FAUNAL LISTS OF THE WAPANUCKA LIMESTONE IN THE
ATOKA QUADRANGLE

[Inserted for comparison with each other and with the lists from Goldston's Otterville limestone next following.]

STATION 3986.—Wapanucka limestone (basal part), Atoka quadrangle. Basal 15 feet of Wapanucka limestone. Layers interbedded with greenish soft shales. One mile SE. of Bromide, Okla.

<i>Enchostoma</i> sp.	<i>Anthraconeilo kessleriana</i>
<i>Leioclema</i> ? sp.	<i>Parallelodon</i> aff. <i>obsoletum</i>
<i>Meekopora</i> ? sp.	<i>Aviculipecten</i> aff. <i>occidentalis</i>
<i>Crania</i> ? sp.	<i>Myalina orthonotus</i>
<i>Orthotetes</i> sp.	<i>Pteria</i> ? sp.
<i>Productus</i> n. sp. aff. <i>pertenuis</i>	<i>Pteria</i> n. sp.
<i>Pustula</i> aff. <i>symmetrica</i>	<i>Pteria</i> ? sp.
<i>Dielasma</i> sp.	<i>Solenopsis</i> n. sp.
<i>Spirifer rockymontanus</i>	<i>Solenomya</i> ? <i>sharonensis</i>
<i>Spiriferina</i> aff. <i>spinosa</i>	<i>Astartella</i> n. sp.
<i>Composita subtilita</i>	<i>Schizodus</i> sp.
<i>Hustedia brentwoodensis</i>	<i>Laevidentalium</i> sp.
" <i>mormoni</i>	<i>Bellerophon crassus</i> ?
<i>Prothyris carinata</i>	<i>Bellerophon</i> n. sp.
<i>Nucula parva</i>	<i>Bucanopsis</i> aff. <i>cancellata</i>
" <i>subrotundata</i>	<i>Euphemus carbonarius</i>
" <i>elongata</i>	<i>Phanerotrema</i> n. sp.
" aff. <i>anadontoides</i>	" aff. <i>grayvillense</i>
" sp.	<i>Pleurotomaria</i> sp.
<i>Leda meekana</i> ?	<i>Aclisina</i> n. sp.
" n. sp.	" ? sp.
" sp.	<i>Glyptobasis</i> n. sp.
<i>Leda</i> ? (n.g. ?) n. sp.	<i>Schizostoma catilloides</i>
<i>Yoldia</i> n. sp.	<i>Bulimorpha</i> n. sp.
<i>Yoldia</i> n. sp.	<i>Nautilus</i> sp.
<i>Yoldia</i> ? n. sp.	<i>Gastrioceras</i> sp.
<i>Yoldia fabula</i>	<i>Griffithides</i> sp.

STATION 4046.—Wapanucka limestone (main bed). Atoka quadrangle. Near south line of sec. 4, near center, T. 2 S., R. 8 E. 1 mile \pm SE. of Bromide, Okla. (Bromide is the name of a town just east of the place indicated on geographic sheet as Sulphur Springs). Fossils from the massive oolite of the Wapanucka limestone.

Crinoidal fragments	Aviculipecten aff. hertzeri ?
Echinocrinus sp.	" n. sp.
Enchostoma sp.	" aff. occidentalis
Stenopora sp.	Pernipecten aviculatus ?
Fenestella sev. sp.	Pseudomonotis kansasensis ?
Polypora sev. sp.	Monopteria polita ?
Septopora sp.	Myalina subquadrata ?
Rhombopora sp.	" orthonotus
Glyptopora crassistoma	" Swallowi ?
Schizophoria aff. resupinoides	Pleurophorus tropidophorus
Derbya n. sp.	Pleurophorus sp.
Pustula aff. pustulosa	Pleurotomaria n. sp. aff. spironema
" ? sp.	Goniospira sp.
Marginifera ? muricata var.	Euconospira n. sp. ? cf. bicarinata
Tegulifera ? sp.	Murchisonia sp.
Spirifer rockymontanus	Aclisina n. sp.
Spirifer ? n. sp.	Eotrochus n. sp.
Composita subtilita	Bulimorpha sp.
Hustedia mormoni	Trachydomia wheeleri ?
Edmondia sp.	Gastrioceras sp.

FAUNAL LISTS OF THE GLENN FORMATION IN THE ARDMORE QUADRANGLE

GOLDSTON'S OTTERTVILLE LIMESTONE

STATION 4056.—Glenn formation ("Otterville limestone"). Ardmore quadrangle, along E.-W. road, center of south edge of sec. 2. T. 3 S., R. 2 E. About 3 miles a little north of northwest from Berwyn, Okla.

Lophophyllum ? sp.	Nucula parva ?
Cladochonus fragilis ?	" subrotundata ?
Agassizocrinus ? sp.	Nuculopsis ? sp.
Delocrinus ? sp.	Leda meekana
Rhopalonaria ? sp.	" inflata
Leioclema n. sp.	Leda ? (n.g. ?) n. sp.
Fenestella tenax	Yoldia n. sp.
Prismopora concava	Yoldia n. sp.
Cystodictya aff. brentwoodensis	Aviculipecten sp.
Rhombopora sp.	Solenomya ? sharonensis
Schizophoria aff. resupinoides	Astartella ? sp.
Chonetes aff. glaber	Phanerotrema n. sp.
Productus aff. coloradoensis	Worthenia ? n. sp.

<i>Productus cora</i>	<i>Pleurotomaria</i> n. sp.
" <i>aff. gallatinensis</i>	" n. sp.
<i>Pustula symmetrica</i>	<i>Pleurotomaria</i> sp.
<i>Marginifera muricata</i>	<i>Bellerophon crassus</i> ?
<i>Spirifer rockymontanus</i>	<i>Bucanopsis aff. meekana</i>
<i>Spiriferina aff. spinosa</i>	<i>Euphemus carbonarius</i>
<i>Composita subtilita</i>	<i>Naticopsis</i> sp.
<i>Hustedia brentwoodensis</i>	<i>Glyptobasis</i> ? n. sp.
" <i>mormoni</i> ?	<i>Schizostoma catilloides</i>
<i>Edmondia</i> sp.	<i>meekospira peracuta</i>
<i>Cardiomorpha</i> ? sp.	<i>Orthoceras</i> sp.
<i>Parallelodon obsoletum</i>	<i>Nautilus</i> sp.
" <i>sangamonense</i>	<i>Goniaites</i> sp.
<i>Nucula elongata</i>	<i>Griffithides</i> sp.

STATION 4062.—Glenn formation ("Otterville limestone"). Ardmore quad-range SW. of NE. corner of sec. 6, T. 6 S., R. 2 E., in very small draw or dry streamlet channel. Beside secondary road. East of Overbrook, Okla.

<i>Cladochonus fragilis</i> ?	<i>Parallelodon pergibbosum</i> ?
<i>Echinocrinus</i> sp.	<i>Aviculipecten aff. occidentalis</i>
<i>Leioclema</i> sp.	" n. sp.
<i>Fenestella tenax</i>	<i>Aviculipecten</i> sp.
<i>Prismopora concava</i> ?	<i>Myalina orthonotus</i>
<i>Cystodictya aff. brentwoodensis</i>	<i>Solenomya</i> ? <i>sharonensis</i>
<i>Schizophoria aff. resupinoides</i>	<i>Pleurophorus</i> sp.
<i>Derbya</i> n. sp. ?	<i>Astartella</i> sp.
<i>Productus cora</i>	<i>Laevidentalium</i> sp. ?
" <i>aff. inflatus</i>	<i>Bellerophon crassus</i>
<i>Pustula nebraskensis</i> ?	<i>Bucanopsis aff. meekana</i>
<i>Marginifera muricata</i>	<i>Euphemus carbonarius</i>
<i>Spirifer rockymontanus</i>	<i>Phanerotrema</i> n. sp.
<i>Spiriferina kentuckyensis</i> ?	" <i>aff. grayvillense</i>
<i>Composita subtilita</i>	<i>Pleurotomaria</i> n. sp.
<i>Hustedia mormoni</i>	" n. sp.
" <i>brentwoodensis</i> ?	<i>Pleurotomaria</i> sp.
<i>Edmondia</i> sp.	<i>Naticopsis nana</i> ?
<i>Nucula subrotundata</i>	<i>Platyceras aff. pulchellum</i>
" <i>parva</i> ?	<i>Schizostoma catilloides</i>
" <i>elongata</i>	<i>Aclisina</i> sp.
<i>Leda meekana</i>	<i>Sphaerodoma</i> sp.
" <i>inflata</i> ?	<i>Meekespira peracuta</i>
" n. sp.	<i>Orthoceras</i> sp.
<i>Leda</i> ? (n.g. ?) n. sp.	<i>Goniatites</i> sp.
<i>Yoldia</i> n. sp.	<i>Griffithides</i> sp.
<i>Anthraconeilo kessleriana</i>	

GOLDSTON'S "CUP-CORAL MEMBER"

STATION 4035.—Glenn formation ("Cup-coral member") Ardmore quadrangle.

Top. of hill NW. of Glenn, Okla. SW. $\frac{1}{4}$ of SE. $\frac{1}{4}$ sec. 4, T. 3 S., R. 1 E.

Campophyllum torquium	Spirifer cameratus
Crinoidal fragments	Squamularia perplexa
Fistulipora sp.	Composita subtilita
Phractopora sp.	" n. sp. ?
Lingulidiscina illinoisensis ?	Cliothyridina orbicularis
Chonetes aff. granulifer	Acanthopecten carboniferus
Productus cora	Pleurotomaria ? sp.
" coloradoensis	Goniospira sp.
Pustula semipunctata	Anomphalus rotulus ?
" nebraskensis	Platyceras n. sp.
Marginifera wabashensis	Nautilus ? sp.
Dielasma bovidens	Griffithides scitulus
Spirifer rockymontanus	Ostracoda

STATION 4035-A.—Glenn formation ("Cup-coral member") Ardmore quadrangle. Same locality but about 40 ft. below 4035. Mainly shale here.

Campophyllum torquium	Productus cora
Lophophyllum profundum	Pustula nebraskensis
Eupachyrinus tuberculatus ?	Marginifera wabashensis
Hydreionocrinus acanthophorus	Spirifer cameratus
" mucrospina	Spiriferina kentuckyensis
Crinoid stems and plates	Squamularia perplexa
Fistulipora sp.	Composita subtilita
Stenopora carbonaria	Allerisma terminale
Fenestella sp.	Yoldia ? sp.
Pinnatopora sp.	Myalina swallowi
Polypora sp.	Schizodus ? sp.
Septopora sp.	Astartella sp.
Cystodictya aff. carbonaria	Phanerotrema ? sp.
Prismopora serrata	Schizostoma catilloides
Streblotrypa prisca	Aclisina sp.
Rhombopora lepidodendroides	Zygopleura sp.
Chonetes mesolobus	Orthoceras n. sp.
Productus coloradoensis	

STATION 4055.—Glenn formation ("Cup-coral member") Ardmore quadrangle.

Along north-south section line road a little north of SW. corner of sec. 4, T. 3 S., R. 1 E. About $1\frac{1}{4}$ miles, a little north of west from Glenn, Okla.

Campophyllum torquium	Composita subtilita
Productus coloradoensis	Cliothyridina orbicularis
" cora	Pseudomonotis hawni var. equistriata
Marginifera wabashensis	Pleurotomaria sp.
Spirifer rockymontanus	Orthoceras sp.

STATION 4063.—Glenn formation ("Cup-coral member"). Ardmore quadrangle. Along township line road, south edge of SW. $\frac{1}{4}$ sec. 34, T. 4 S., R. 1 E. About $3\frac{1}{2}$ miles west and 1 mile south of the center of Ardmore, Okla.

Crinoid stems and plates	<i>Lima retifera</i>
<i>Rhipidomella carbonaria</i>	<i>Astartella</i> sp.
<i>Schizophoria</i> sp.	<i>Bellerophon</i> sp.
<i>Chonetes granulifer</i>	<i>Pleurotomaria</i> n. sp. aff. <i>persimplex</i>
" <i>levis</i>	" aff. <i>scitula</i>
<i>Productus coloradoensis</i>	" sp.
" <i>cora</i>	<i>Bulimorpha</i> sp.
<i>Pustula semipunctata</i>	<i>Sphaerodoma</i> sp.
" n. sp.	<i>Platyceras occidentale</i>
<i>Spirifer rockymontanus</i>	<i>Anomphalus rotulus</i> ?
<i>Squamularia perplexa</i>	<i>Orthoceras</i> sp.
<i>Nuculopsis ventricosa</i>	<i>Nautiloid</i>
<i>Yoldia</i> aff. <i>stevensoni</i>	<i>Paralegoceras iowense</i>
<i>Parallelodon tenuistriatum</i>	<i>Goniatites</i> aff. <i>lunatus</i> ?
<i>Euchondria neglecta</i> ?	<i>Gastrioceras</i> aff. <i>nolinense</i>

GOLDSTON'S DEESE MEMBER

STATION 4050.—Glenn formation ("Deese member") Ardmore quadrangle. About $\frac{3}{4}$ mile north of Deese, Okla. Center west edge of sec. 32, T. 3 S., R. 1 E.

<i>Axophyllum rude</i>	<i>Edmondia</i> sp.
Crinoid fragments	<i>Nucula anadontoides</i>
<i>Echinocrinus cratis</i> ?	<i>Leda bellistriata</i>
<i>Derbya affinis</i>	<i>Astartella</i> aff. <i>gurleyi</i>
<i>Chonetes granulifer</i>	<i>Dentalium semicostatum</i>
" <i>mesolobus</i> var. <i>decipiens</i>	<i>Bellerophon stevensianus</i> ?
<i>Tegulifera</i> ? <i>kansasensis</i>	<i>Trepostira</i> ? sp.
<i>Pustula nebraskensis</i>	<i>Pleurotomaria</i> sp.
<i>Squamularia perplexa</i>	" sp.
<i>Composita subtilita</i>	<i>Meekospira peracuta</i>
<i>Cliothyridina orbicularis</i>	<i>Pseudorthoceras knoxense</i>

STATION 4054.—Glenn formation ("Deese member"). Ardmore quadrangle. Along section line road a little north of west $\frac{1}{4}$ corner sec. 28, T. 3 S., R. 1 E. About $1\frac{3}{4}$ miles north of Deese, Okla., and south of Caddo Creek.

<i>Productus coloradoensis</i>	<i>Pustula symmetrica</i> ?
<i>Pustula semipunctata</i>	

STATION 4058.—Glenn formation ("Deese member"). Ardmore quadrangle. Along section line road between sections 19 and 20, T. 5 S., R. 2 E. and

about $\frac{1}{10}$ mile north of south corner. About 5 miles south of the center of Ardmore, Okla.

Orbiculoides aff. capuliformis	Schizodus sp.
Productus cora	Pleurophorus sp.
Spirifer rockymontanus	Bellerophon ? sp.
Leda sp.	Euphemus ? sp.
Deltopecten occidentalis ?	Phanerotrema ? sp.
Pteria ohioensis	Goniospira sp.
Pseudomonotis sp.	Nautilus sp.
Schizodus insignis ?	

STATION 4059.—Glenn formation ("Deese member"). Ardmore quadrangle.

Limestone near top of Deese member of the Glenn. Near the SE. corner of sec. 28, T. 5 S., R. 2 E. $\frac{1}{2}$ mile N. and $2\frac{1}{2}$ miles west of Hoxbar, Okla.

Septopora biserialis	Naticopsis sp.
Rhombopora lepidodendroides	Naticopsis ? sp.
Composita subtilita	Schizostoma catilloides
Myalina subquadrata	Aclisina sp.
Bellerophon sp.	Aclisina sp.
Phanerotrema ? sp.	Zygopleura n. sp.
Pleurotomaria sp.	Cyclonema sp.

GOLDSTON'S HOXBAR MEMBER

STATION 4060.—Glenn formation ("Hoxbar member"). Ardmore quadrangle.

Just west of Anadarche Creek on small ridge. Just west of SE. corner sec. 27, T. 5 S., R. 2 E. About $1\frac{1}{2}$ miles west and $\frac{1}{2}$ mile north of Hoxbar, Okla., along road.

Fusulina sp.	Squamularia perplexa
Spirifer triplicatus	Composita subtilita

Beds mapped as "Springer member" but believed to be almost certainly younger than Goldston's Otterville limestone and possibly younger than any known faunal zone in the section. Lots 4064 and 4065 are closely related faunally. Lot 4061 has an appreciably different fauna, though it is not necessarily younger. Poor preservation renders the identification of this collection more or less difficult and uncertain.

LOT 4064.—Glenn formation ("Springer member" as mapped). Ardmore quadrangle, near the center of the east edge of the NE. $\frac{1}{4}$ of SE. $\frac{1}{4}$ sec. 2, T. 6 S., R. 1 E.

Crinoid fragments	Myalina subquadrata
Echinocrinus sp.	" kansasensis ?
Polypora sp.	Pseudomonotis equistriata

<i>Septopora biserialis</i> ?	<i>Schizodus</i> sp.
<i>Rhombopora lepidodendroides</i>	<i>Pharkidonotus percarinatus</i>
<i>Derbya crassa</i>	<i>Bucanopsis meekana</i> ?
<i>Productus insinuatus</i>	<i>Euphemus nodicarinatus</i>
<i>Pustula nebraskensis</i>	<i>Phanerotrema grayvillense</i> ?
<i>Spirifer cameratus</i>	<i>Pleurotomaria</i> sp.
<i>Spiriferina kentuckyensis</i>	<i>Goniospira lasallensis</i> ?
<i>Composita subtilita</i>	<i>Naticopsis</i> sp.
<i>Sanguinolites costatus</i> ?	<i>Goniatites</i> ? sp.
<i>Deltopecten occidentalis</i>	

Lot 4065.—Glenn formation ("Springer member" as mapped). Ardmore quadrangle, a little less than $\frac{1}{4}$ mile north of No. 99 (4064). Stratigraphically this coll. is about 90 feet lower.

<i>Wewokella solida</i>	<i>Composita subtilita</i>
Crinoidal fragments	<i>Allerisma terminale</i> ?
<i>Echinocrinus</i> sp.	<i>Edmondia aspinwallensis</i>
<i>Fistulipora carbonaria</i>	" <i>gibbosa</i>
<i>Septopora biserialis</i> var. <i>nervata</i>	<i>Chaenomya cooperi</i>
<i>Rhombopora lepidodendroides</i>	<i>Myalina kansasensis</i>
<i>Productus cora</i>	<i>Pinna peracuta</i>
" <i>insinuatus</i> ?	<i>Schizodus affinis</i>
" <i>semireticulatus</i>	<i>Pharkidonotus percarinatus</i>
<i>Pustula nebraskensis</i>	<i>Bucanopsis meekana</i>
<i>Spirifer triplicatus</i>	

Lot 4061.—Glenn formation ("Springer member" as mapped). Ardmore quadrangle, 5 miles west and $1\frac{1}{2}$ miles south from the center of the center of Ardmore, Okla. Near center of west edge of sec. 4, T. 5 S., R. 1 E.

<i>Pustula nebraskensis</i>	<i>Pseudomonotis</i> ? aff. <i>equistriata</i>
<i>Composita subtilita</i>	" ? sp.
<i>Aulacorhynchus millepunctatum</i> ?	<i>Schizodus meekanus</i> ?
<i>Leda arata</i>	<i>Bucanopsis bella</i>
<i>Nucula parva</i>	<i>Goniospira lasallensis</i>
<i>Deltopecten occidentalis</i>	<i>Naticopsis scintilla</i>
<i>Myalina swallowi</i>	" ? cf. <i>diminutiva</i>
" <i>wyomingensis</i>	<i>Pseudorthoceras knoxense</i> ?

DISCUSSION

W. L. Goldston, Jr.: The sediments of the Glenn formation become more calcareous toward the south. This is true of all the members of the formation. It is especially marked in the Springer member. North of the Ardmore syncline, this division is composed of sand and shales, whereas on the south

side of this basin, in the vicinity of the Criner Hills, a number of limestone beds occur in it. I recall one or two localities in the Ardmore area where it is possible to walk an outcrop of conglomerate and observe the change from conglomerate to sandstone and from sandstone to shale within the short distance of three miles. After seeing this rapid change in sediment, it is not absurd to correlate the limestone beds in the vicinity of the Criner Hills as stratigraphically equivalent to some of the shales in the Springer member twenty miles to the north. This rapid change in character of sediment evidently continues southward, for in Texas the equivalent of the Glenn is represented by the Bend, Strawn, and Canyon formations. The 16,000 to 19,000 feet of shales and sands have thinned to 3,000 feet of sediments in which limestone members are prominent.

This rapid change in sediment makes difficult, but not impossible, the correlation of the Glenn members on the north and south sides of the Ardmore syncline. In the *Camphophyllum torquium* member north of the Ardmore syncline, there is a limestone bed which carries an abundance of *Spirifer condor*.¹ South of the syncline, this fossil occurs in a chert member. At about an equal interval below these *Spirifer condor* horizons, on both sides of the syncline, there occurs a 1,600-foot black shale. This black shale and the *Spirifer condor* horizons were used as markers for correlating the beds. North of Ardmore the black shale forms the upper part of the Springer member. Accordingly, in the vicinity of Criner Hills, the sediments below and including this shale were mapped as the basal part of the Pennsylvanian or belonging to the Springer member.

There is also a structural reason for correlating the sediments immediately surrounding the Criner Hills with those of the Springer member.

A section from the Arbuckle Mountains to the Criner Hills through the town of Glenn shows the following exposures and repetition of members: From the Arbuckle Mountains to the Glenn syncline the Springer, Otterville limestone, *Camphophyllum torquium*, and probably a portion of the basal part of the Deese members, are exposed. From this syncline to the axis of the Ardmore anticline, this section is repeated. From the axis of the Ardmore anticline to the basin of the Ardmore syncline, these members are repeated the third time with an addition of the Deese member, which, west of the town of Ardmore, forms the trough of the basin. South of the Ardmore syncline the rocks dip away from the Criner Hills and into the basin. One bed lies successively below the other without any evidence of repetition. It is natural to suppose the older bed lay beneath the younger ones. From a carefully measured section, the thickness of this series of sediments is estimated at from 11,000 to 13,000 feet. This checks very closely with the total aggregate of sediments forming the Glenn members north of the Ardmore basin. It is

¹ Cheironym, undescribed species of D. K. Greger ? Editor.

natural, therefore, to suppose that in the 11,000 to 13,000 feet of sediment south of the Ardmore syncline, each member of the Glenn formation is represented.

With these data at hand, it is difficult to understand how the Pennsylvanian sediments surrounding the Criner Hills can be classified as other than those belonging to the Springer member of the Glenn formation. To show that these rocks are younger than the Springer member, it will be necessary to prove and explain the following: (1) The Ardmore syncline does not exist. (2) The 12,000 feet of sediments between the Ardmore syncline and the Criner Hills are completely overturned, the younger sediments now dipping beneath the older ones. (3) The Criner Hills uplift came at a much later period than the Arbuckle Mountains uplift.

THE RELATION OF QUALITY OF OIL TO STRUCTURE AT EL DORADO, ARKANSAS¹

HENRY A. LEY

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Marked differences in the character of crude oils from different parts of the United States and from different parts of the same producing horizon have been known for many years. During these years the chemist has been determining the physical and chemical properties of practically all crude oils produced in the United States, and the geologist has been studying their geologic occurrence. Unfortunately, each has worked primarily for commercial purposes, and has pursued the investigation from his own point of view and line of attack. The chemist determined the proportion of refined products which the crude oil might yield upon distillation and the method of procedure to be followed during the refining process; while the geologist, on the other hand, largely focused his attention upon the attitude and character of the oil-bearing rocks in an effort to discover new oil fields. It is surprising how few cases there are where the results of these two lines of investigation, though undertaken in the same field or pool, have been coordinated. This geochemical approach to the solution of many of our oil field problems is apparently seldom considered, though it offers many opportunities for intimate studies of the genesis and accumulation of oil and gas, and may reveal principles that have valuable commercial applications.

During the course of a geologic study of the El Dorado, Arkansas, oil and gas field in March, 1921, the writer was impressed by the fact that the Baume gravity of the crude oil as well as the Baume gravity of the first 20 per cent of distillate varied from well to well.² In order to detect any regularity in the distribution of

¹ Published by permission of Mr. J. Edgar Pew, vice-president, and Dr. F. H. Lahee, chief geologist, of the Sun Oil Company, Dallas, Texas.

² The analyses of El Dorado crude oils shown on the accompanying map were made by I. L. Klein, chief chemist of the Toledo refineries of the Sun Oil Company.

these gravities, if such did occur, the Baumé gravity of the crude oils, which had been analyzed, was plotted opposite the map location of the wells and lines were drawn through points of the same Baumé gravity at 1 degree intervals. A similar map was constructed using regular intervals of Baumé gravity of the first 20 per cent of distillate. These maps were then superimposed on a structure contour map of the top of the Nacatoch pay sand. This comparison showed a relation between the quality of the crude oil and structure, and at the same time suggested a possible commercial application, which the writer believes may be of value to geologists and operators engaged in the development of new oil fields in regions where faulting primarily controls the migration and accumulation of oil or gas. It is not the object of this paper to reduce this geochemical phenomenon to its simplest elements and determine the cause of the observed relations, for the writer has only the few analyses which Mr. Klein made during his brief stay at El Dorado. But rather the object is to describe the phenomenon and to suggest a possible commercial application with the object of stimulating general interest in similar geochemical problems.¹

PREVIOUS WORK

The more important contributions to the geochemical literature of our oil fields have been by G. Sherburne Rogers, Fred B. Tough, and others, H. W. Bell and R. A. Cattell, David White, and A. W. McCoy.

G. S. Rogers² has probably made the most complete contribution to this subject. In the paper cited he has assembled many analyses of the oil, gas and oil field waters of the Sunset-Midway oil field, and discusses their composition in relation to their geologic occurrence.

F. B. Tough, S. H. Willison, and T. E. Savage³ published the first map, of which the writer has knowledge, showing contours on

¹ Gravity data are now much more conveniently available since almost all crude oils are purchased in the field on a gravity basis.

² G. S. Rogers, "The Sunset-Midway Oil Field," *U. S. Geol. Survey, Prof. Paper* 117, 1919.

³ Fred B. Tough, Samuel H. Willison, and T. E. Savage, "Experiments in Water Control in the Flat Rock Pool, Crawford County, Illinois," *State Geol. Survey, Bull.* 40, 1919.

Baumé oil gravities. They call attention to the fact that the lighter oils of the Fat Rock oil pool of Crawford County, Illinois, are almost entirely restricted to the higher parts of the structure, which in this case was also the center of the pool.

Bell and Cattell¹ in July, 1921, were first to call attention to the fact that there was considerable variation in the gasoline content of the gas in the Monroe gas field—the gasoline content increasing southeastward until it reaches a maximum along a northeast to southwest trending fault. In this case the gases of the higher parts of the Monroe uplift were “dry.”

Swigart,² without attempting to explain the difference, states that in the Hewitt oil field of Oklahoma “there is a slight evidence that the wells on the south and southeast flanks produce the lightest oils while those near the top of the structure produce slightly heavier oil.”

Pack³ concludes that the variation of the gravity of the Sunset-Midway oils “seems to bear some relation to the structure, to the presence of water, and to the depth of the oil sand beneath the surfaces.”

David White⁴ believes that the degree of regional metamorphism to which the contained rocks have been subjected determines the character of the oil. This view, however, is questioned by McCoy,⁵ who asks whether “such a change in the carbon ratio might not be the result of original sedimentation or the process of drying and solidification before the sediments are deeply buried, rather than to metamorphism from mountain movement.”

¹ H. W. Bell and R. A. Cattell, “The Monroe Gas Field, Ouachita, Morehouse, and Union Parishes, Louisiana,” *Dept. of Conservation, State of Louisiana, Bull.* 9, 1921.

² T. E. Swigart and F. X. Schwarzenbek, “Petroleum Engineering in the Hewitt Oil Field,” U. S. Bur. Mines paper published in co-operation with the State of Oklahoma, and the Ardmore Chamber of Commerce, 1921.

³ R. W. Pack, “The Sunset-Midway Oil Fields,” *U. S. Geol. Survey, Prof. Paper* 116, pp. 86-87, 1920.

⁴ David White, “Some Relations on Origin between Coal and Petroleum,” *Washington Acad. Sci. Jour.*, Vol. V (1915), pp. 189, 212.

⁵ A. W. McCoy, “A Short Sketch of the Paleo-Geography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology,” *Bull. Am. Assoc. Pet. Geol.*, Vol. V (1921), No. 5, p. 570.

LOCATION AND EXTENT OF THE FIELD

The El Dorado field is situated in the central part of Union County, Arkansas, about 12 miles north of the Arkansas-Louisiana state boundary, adjacent to the town of El Dorado.

An area of approximately 5,000 acres has afforded oil in commercial quantities, while fully 2,000 acres in the extreme north-western part of the field were regarded as gas territory. The field is long and narrow. It extends in a west of north and east of south direction from Sec. 26, T. 17 S., R. 16 W., to Sec. 16, T. 19 S., R. 15 W.—a distance of about 10 miles.

HISTORY OF DEVELOPMENT

For many years southern Arkansas attracted very little attention as prospective oil territory. In April, 1920, the Constantine Refining Company, completed their Armstrong No. 1 well in Sec. 1, T. 18 S., R. 16 W., with an estimated initial open flow capacity of 30,000,000 cubic feet of gas daily and a trace of oil. But it was not until January 10, 1921, when the Mitchell and Busey well came in with an estimated initial flow of about 5,000 barrels of fluid—1,500 barrels of oil and 3,500 barrels of water—and a large volume of gas, that an impetus was given to leasing and development. From that time on the field was rapidly developed, and the average daily production climbed to a maximum of 77,000 barrels during the week of August 12, 1921. Since that time production has steadily declined to an average of 14,320 barrels daily during the week ending March 8, 1923. All the wells have yielded water along with the oil or gas, either from the time of their completion, or shortly after. In October, 1921, eight months after the completion of the first commercial oil well, the United States Bureau of Mines¹ estimated that at least one-third of the gross production was water. This water came from immediately below the oil-bearing beds in wells producing on the higher parts of the structure, and from the oil-bearing beds themselves in wells situated on the flanks of the structure. The wells were commonly drilled into pay sand and completed by the rotary method.

¹ H. W. Bell and J. B. Kerr, "The El Dorado, Arkansas, Oil and Gas Field," U. S. Bur. of Mines in co-operation with the Arkansas State Bur. of Mines, 1922.

GEOLOGIC CONDITIONS

Stratigraphy.—The relatively unconsolidated bedrock outcrops of sands and clays of this district belong to the Upper Claiborne group of the Eocene Tertiary. The thin veneer of gravel frequently found on the uplands are the redeposited remnants of Pliocene material. In the valleys these bedrock exposures are generally covered with surficial deposits of residual or alluvial sands and silts of the Pleistocene and Recent series of the Quaternary system. Below the Upper Claiborne beds in geological sequence, the drill penetrates about 1,400 feet of the Wilcox, and Midway formations of the Eocene Tertiary, and about 600 feet of Arkadelphia clays—Gulf series of the Upper Cretaceous. The Nacatoch sand, present immediately beneath the Arkadelphia clays, is encountered at depths ranging from 2,000 to 2,200 feet.

Oil-bearing zone.—The oil of this district is chiefly derived from sandy beds of the Nacatoch formation. At its outcrop, about 60 miles northwest, the Nacatoch formation consists largely of glauconitic sands and calcareous sandstones. In the El Dorado district this formation consists of loosely consolidated sands, sandstones, and sandy limestones. The oil-bearing beds, consisting of loosely consolidated sands, thin and thicken abruptly. They are confined to the upper 50 feet of the Nacatoch section and seldom exceed 15 feet in thickness. In the northern part of the field a hard impervious cap rock overlies the oil-bearing zone, while in the central and southern parts of the field the drill passes from soft impervious clays directly into the oil-bearing sands.

Structure.—In general, the surface beds of southern Arkansas slope gently southward toward the Gulf of Mexico or southeastward toward the Mississippi embayment. Mapping of surface structure in this district is at best very unsatisfactory.¹ Clinometer work is

¹ There are three excellent examples of oil fields situated in the Eocene Tertiary belt of the Gulf Coastal Plain Province which have or could have been outlined by surface geology. They are: the Haynesville, Louisiana, field, an anticlinal structure outlined by quaquaversal dips; the Bellevue area of Bossier Parish, Louisiana, where a fold is shown by the presence of a Wilcox inlier surrounded by Lower Claiborne beds; and the Mexia, Texas, field, where either faulting or sharp folding is immediately suggested by the presence of sandy Wilcox beds between the Mexia and Tehuacana outcrops of the Midway limestone.

extremely uncertain because of the highly cross-bedded character of many of the exposures. Determination of surface structure by the areal distribution of beds or formations is quite difficult in view of the gradual change in the color and texture of the material from bed to bed and even from formation to formation.

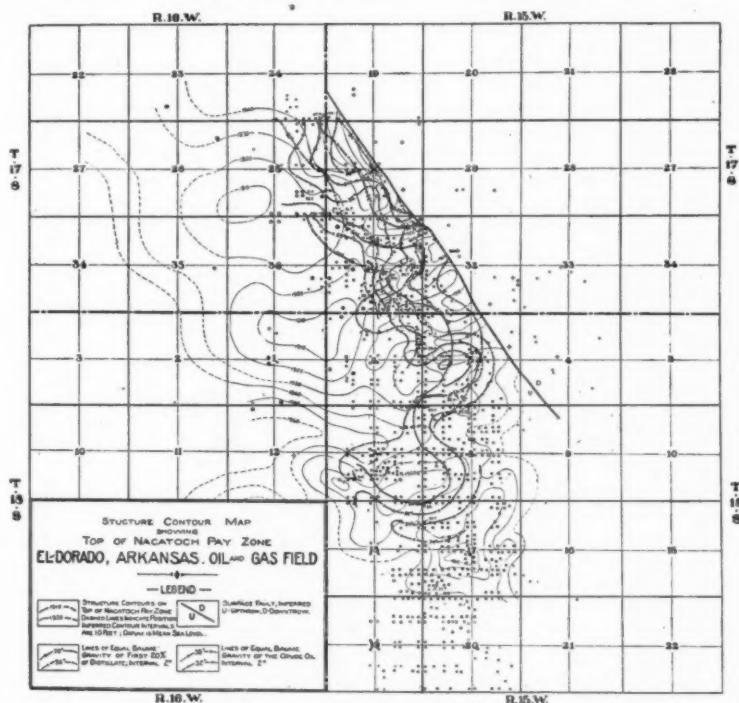


FIG. 1

Those who have worked in this district commonly regard the El Dorado structure as an anticline which extends from Sec. 6, T. 17 S., R. 16 W., southeastward to and possibly beyond Sec. 9, T. 19 S., R. 15 W. (see Fig. 1). The top of this field is comparatively flat with a number of irregular "closures" along its major axis. The higher parts of the structure are found in the southwest quarter of Sec. 25, T. 17 S., R. 16 W., the northeast quarter of

Sec. 1, T. 18 S., R. 16 W., the southeast quarter of Sec. 7, T. 18 S., R. 15 W., and south half of Sec. 17, T. 18 S., R. 15 W. The closure of the main structure amounts to at least 35 feet and probably more when the contours are extended so as to include adjacent wildcat tests.

It is interesting to note the large number of dry holes which define the productive area of this field on the east. A line drawn between the westernmost dryholes and the easternmost oil wells approximately coincides with the trace of a fault or fault zone which displaces the beds along the east flank of the anticline. The existence of such a fault or fault zone seems to be clearly demonstrated. Wells to the west of this line find the Nacatoch sand comparatively high, whereas those to the east find it low. The light oils are only found west of this line, while only heavy oils are found to the east. This line, which many accept as the trace of a fault or fault zone of relatively low vertical displacement, extends southeastward from the vicinity of Sec. 19, T. 17 S., R. 15 W., to and possibly beyond Sec. 4, T. 18 S., R. 15 W.

Relation of production to structure.—The El DoraJo field is a striking example of an anticlinal accumulation where faulting has played an important rôle in the migration and accumulation of oil and gas. Figure 1 shows clearly that the gas is largely confined to the highest parts of the structure in parts of Secs. 25, 26, 35, and 36 T. 17 S., R. 16 W., Sec. 1, T. 18 S., R. 16 W., and Sec. 6, T. 18 S., R. 15 W. In the northern part of the field there are a number of wells which when they were first drilled were gas wells. These wells may not all be shown on the map, inasmuch as some of them produced oil later. The oil lies almost wholly on the east flank of the anticline. North of Sec. 7, T. 18 S., R. 15 W., the oil accumulation extends westward from the fault to points about midway between the fault and the major axis of the structure. South of this point the oil has accumulated westward from the fault on the east flank, along the major axis, and well down the western slope of the anticline.

RELATION OF THE QUALITY OF OIL TO STRUCTURE

Figure 1 is a structure contour map of the top of the Nacatoch pay zone on which has been placed (1) lines of equal Baumé gravity of the crude oil, and (2) lines of equal Baumé gravity of the first 20

per cent of distillate for the purpose of bringing out the definite relation of the quality of El Dorado oils to the structure.

The dash and "x" lines connect points of equal Baumé gravity of the crude oil ranging from 28 degrees or less to 36 degrees or more. The dash and dot lines connect points of equal Baumé gravity of the first 20 per cent of distillate ranging from 58 degrees or less to 62 degrees or more. It may be observed that the structure is markedly anticlinal, that the major axis of the anticline trends west of north and east of south; that the irregular areas of structure "closure" attain approximately the same elevation—1,910 feet below sea level; and that the fault which cuts the east flank of the anticline in general parallels the major anticlinal axis. The figure shows that the higher parts of the structure in the northern part of the field are largely gas bearing and the oil-bearing area extends eastward, from points about midway between the anticline axis and the fault, to the fault; while in the central and southern parts of the field the oil-bearing area lies on the west slope, covers the axis of the fold, and extends eastward to the fault; and the eastern limits of the field are sharply defined by "dry" holes.

By comparing the lines of equal gravity with the structure of the field we find that they tend to parallel the major axis of the anticline and the trace of the fault, and that they increase eastward toward the fault, so that the lightest oils lie immediately adjacent to the fault zone. These lines of equal gravity seem to be deflected away from the minor areas of anticlinal bowings or "closures" of the contours, and are drawn into the synclinal areas. While the Baumé gravities of the crude oil and distillate tend to parallel the fault and the axis of the anticline, they do not exactly parallel each other, but rather tend to undulate gently across one another. On closer examinations it is seen that the lines of equal Baumé gravity of the first 20 per cent distillate (regarded by chemists as an index of the gasoline content of an oil) tend to parallel the fault while those of the crude oil conform more closely to the structure contours. This is a graphic statement of a fact which I. L. Klein observed in his chemical analyses, that the gravity of the crude does not always represent its gasoline content, or in other words a light gravity crude will sometimes have less gasoline than a heavier crude.

ECONOMIC APPLICATION

The oil industry primarily exacts of the geologist adequate returns on the aggregate expenditures for which he is responsible. Today there is an increasing tendency for population to outstrip the natural resources at its disposal and for industries to operate on a large scale in order to secure increasing returns and to maintain a fair rate of return on the investment over a period of years. In other words, though the operator, whether an individual or corporation, may expect an increasing demand for his crude oil or petroleum products, the margin of his profit will be constantly reduced by the competition of large-scale production. One of the most important ways by which society, the individual operator, or corporation can minimize these conditions is by the application of scientific research—work which will seek to improve the methods of production, more completely master nature's secrets, and more efficiently utilize the natural resources.

The margin of profit which may be secured from oil properties of the same daily production situated in the same field or pool may vary considerably when the oil is sold on a gravity basis. The manner in which the purchase of oil on a gravity basis by the pipeline companies can spell success or failure for an operator becomes quite evident in the case of the El Dorado field.¹

On March 15, 1923, the pipe-line companies were purchasing El Dorado oil on the following posted schedule of Baumé gravities:

¹ Similar conditions prevail in the Smackover field. Previous to March 8, 1923, the crude was graded and purchased on the following basis:

26.0 degree gravity and up.....	\$1.35
All grades below 26.0 degrees gravity.....	.90

Effective March 8, 1923, the Standard Oil Company of Louisiana posted a new Baumé gravity grading of Smackover crude as follows:

Below 22.0 degrees.....	\$.90
22.0 degrees to 23.9 degrees.....	1.00
24.0 degrees to 24.9 degrees.....	1.10
25.0 degrees to 25.9 degrees.....	1.20
26.0 degrees and up.....	1.35

Thus there is a range of 45 cents per barrel in the selling price of Smackover crude in 4 degrees of Baumé gravity which permits the producer of highest grade oils to receive 50 per cent more for his production than the producer of the lowest grade oils.

Below 30 degrees.....	\$1.35
30.0 degrees to 32.9 degrees.....	1.70
33.0 degrees to 34.9 degrees.....	1.85
35.0 degrees to 36.9 degrees.....	2.00
37.0 degrees to 38.9 degrees.....	2.20
39.0 degrees and above.....	2.40

Thus in a range of 9 degrees Baumé gravity there is a rate differential of \$1.05—the producer of highest grade receiving about 78 per cent more for his oil than is paid to the producer of 30-degree gravity oil. It follows then that as soon as the operator is able to determine the direction in which the gasoline content of the crude or the Baumé gravities are increasing in a new field he should govern his leasing activities accordingly—paying higher prices, if necessary, for leases which are apt to produce the higher grade oil.¹ In regions where faulting has influenced the migration and accumulation of oil, as in the Tertiary and Cretaceous fields of the Gulf Coastal Plain province, there is an additional advantage to be secured by leasing in the direction of gasoline content increase, namely, that of approaching the more highly productive areas which commonly lie immediately adjacent to the fault zone.

SUMMARY

From the data presented it is evident that in some districts the quality of an oil or gas from a given producing zone of a pool is definitely related to faulting with or without particular reference to folding. This relation is very marked in the El Dorado field of Arkansas, probably explains the southeastward increase in gasoline content of gas at Monroe, Louisiana, and is said to be apparent in the Bull Bayou field of Louisiana. In addition to faulting there may be many factors involving geochemical and physicochemical relations which help to determine the quality of an oil or gas of a particular pool so that the observed phenomenon may represent the sum of the effects of more than one factor. As several, all,

¹ Early in the development of the Smackover area the gravity of the oils appeared to be increasing in a west or southwest direction, indicating that the fault zone, if such existed, would lie to the west and that leasing should be concentrated in an area lying to the west and southwest.

or a combination of factors may be involved in a field or pool, it is evident that a general deduction regarding the relation of quality of oil to structure cannot be made to apply to the producing pools of all the geologic provinces.

The writer believes, however, that the El Dorado relation will hold true for those Cretaceous fields of Arkansas, Louisiana, and Texas, where faulting has similarly influenced migration and accumulation. Before positive conclusions can be formulated each important field of a province must be studied separately with the same object in view. The resulting conclusions will, undoubtedly, be of inestimable value to geologists and producers in selecting the more likely areas of greater returns in a particular pool as well as indicating general structural conditions of a pool. The economic value of the El Dorado relation can be best appreciated in the case of the Smackover field, which is constantly being extended to the west and southwest by larger and larger light oil wells.

DISCUSSION

F. H. LAHEE: This subject is one which could easily lead to extended discussion. I want to mention just one point. At Smackover some of the oil loses one, two, or three degrees Baumé within a few hours or a few days after a well is brought in. This is a phenomenon which should be borne in mind in any studies such as Mr. Ley's. In comparing the gravity of the oil in different wells producing from the same sand in a given field, we must be careful to make measurements under as nearly the same conditions as possible. These measurements of gravity would probably best be made a certain definite number of days, say three or four days, after the well is completed.

K. C. HEALD briefly discussed the structure at El Dorado, questioning the conclusion that the fold is an anticline terminated on the northeast by a fault.

F. JULIUS FOHS defended the anticlinal interpretation of the subsurface structure and discussed the fault.

H. A. LEY: I am fully in accord with the views of Mr. Fohs regarding the position of the fault. There is not sufficient data with which to define exactly the trace of this fault in the Nacatoch sand. East of this fault line the top of the Nacatoch zone is found at most irregular depths from well to well and considerably lower than to the west of the fault line. I thank Mr. Fohs for his defense of the anticlinal structure of the El Dorado field.

Replying to Mr. Heald's statement that the El Dorado field is not located on an anticline, and that instead of the northwest to southeast trending fault

which I have shown there are six subsurface faults trending in a northeast-southwest direction, I wish to state that the common consensus of opinion of oil company geologists who have studied this field and of the United States Bureau of Mines is that the structure is an anticline and that there is a northwest-southeast trending fault. I might add that faults of 5 to 10 feet vertical displacement, as presented by Mr. Heald in the Press Bulletin of the United States Geological Survey, are open to severe criticism when based only on the interpretation of rotary well log correlations of the producing sand. As a rule faults in the Cretaceous fields of the Gulf Coastal Plain province sharply terminate a pool.

C. W. TOMLINSON: I would like to ask Mr. Ley whether he has any data bearing on the relation of variations in gravity to structure in fields not known to be faulted.

H. A. LEY: Yes. The Flat Rock data in Bull. 40 of the Illinois State Geological Survey.

NOTES ON THE STRATIGRAPHY OF PRODUCING SANDS IN NORTHERN LOUISIANA AND SOUTHERN ARKANSAS

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This paper offers a brief general statement of our present knowledge of the geological formations in northern Louisiana and southern Arkansas, based on the literature and observation in the field. However, we cannot exactly describe these formations, whose names we use familiarly every day, for we lack systematic, comprehensive study of the new formations discovered by the drill. Detailed systematic geology cannot keep abreast with exploratory geology and commercial exploitation.

In the search for structure in the Coastal Plain sediments a little knowledge is a dangerous thing, but fortunately for those of us who have not had the opportunity or taken the time really to know the formations drilled, the desired result, production, has nevertheless been generally attained, and producing sands have been found in rapid succession in new fields and in new formations, and our little knowledge has not been tested too severely.

The commercially productive sands in this territory are five in number, from youngest to oldest, (1) Nacatoch, (2) Annona, (3) Blossom, (4) Eagle Ford, and (5) Glen Rose. These names are not always accurately used, nor do they include all the formations that are known to contain oil and gas.

The formations are exposed at the surface along a northeast-southwest strike in southwestern Arkansas and dip rapidly southwestward beneath the surface into extreme southern Arkansas and Louisiana where they flatten out and then rise here and there, forming the oil and gas structures of the territory, such as the Sabine uplift with its fields in Caddo, Bossier, De Soto and Red River parishes, Louisiana, and Panola County, Texas, and the

distinct fields at Stephens, Smackover, and El Dorado, Arkansas, and Homer, Haynesville, Webster, and Monroe, Louisiana.

The five producing formations here mentioned are all Cretaceous. Except on the interior salt domes and on the Bellevue dome in Bossier Parish where the Cretaceous is exposed, or lies just beneath a thin Quaternary veneer, the producing horizons are overlain by Tertiary and Quaternary rocks ranging in thickness from 200 to 1,800 feet.

The formations which overlie the first oil sand, the Nacatoch, have been described by a number of students of this region. The writer desires here to call attention to changed ideas as to our producing sands and associated formations and thus to show the need of a detailed, comprehensive study of the correlation of these formations in Louisiana and Arkansas by a qualified geologist whose research will not be hampered either by the discontinuance of legislative appropriation or by the more or less excusable lack of interest of oil producers.

Omitting the comparatively thin Pleistocene and Pliocene deposits, the formations in the area under consideration are given in Table I.

The Nacatoch was described by Hill¹ in 1888 as the "Washington greensand," which name Veatch² notes would have been retained had it not been preoccupied. Further, the "Washington greensand" seems to have included part of Veatch's underlying Marlbrook formation, the term "Nacatoch," as used by Veatch, being restricted to the sandy beds. The typical exposure at Nacatoch Bluff on Little Missouri River, Clark County, Arkansas, is predominantly sand.

The Nacatoch formation as found by drilling in the oil fields varies considerably in different fields although it is generally recognized without much difficulty by reason of its position just beneath the Arkadelphia clays and shales.

In the Caddo field, the Nacatoch is called "gas rock" and is logged as 100 to 200 feet of sand. At Bellevue, about 25 miles

¹ R. T. Hill, *Geological Survey of Arkansas Annual Report, 1888*, Vol. II, pp. 72-75, 188.

² A. C. Veatch, *U. S. Geol. Survey, Prof. Paper 46*, p. 27, 1906.

southeast of Caddo, the formation is distinguished in places by as much as 70 feet of fossiliferous limestone underlain by the soft

TABLE I
FORMATIONS IN THE OIL AND GAS FIELDS OF NORTHERN LOUISIANA
AND SOUTHERN ARKANSAS

SYSTEM, SERIES, GROUP, FORMATION	PRINCIPAL CHARACTERISTICS	MAXIMUM THICKNESS IN FEET	PRODUCTIVE POOLS
Tertiary, Eocene, Claiborne, (1) Cockfield	Gray sand, some clay, shale, lignite, and quartzitic sandstone, non-marine.	450	
(2) St. Maurice	Limonic clay, sand, cal- careous glauconitic shales, marine	400	
(3) Wilcox	Sand, clay, shale, lignite, calcareous boulders, glau- conitic.	600	
(4) Midway	Clay, limestone, chalk, some lignite, gypsum.	400	
Cretaceous, Gulf (5) Arkadelphia	Dark clay, shale, chalk near bottom, marine.	600	
(6) Nacatoch	Fossiliferous limestone, glauconitic sand	200	Gas at Caddo, Shreveport, Bethany, El Dorado and Smackover. Oil at Homer, El Dorado, Bellevue, and Smack- over
(7) Marlbrook	Marl, chalk	350	
(8) Annona	Chalk	600	Gas at Monroe (?) Oil at Caddo
(9) Brownstown	Marl, chalk.	300	
Bingen, (10) Blossom	Calcareous, glauconitic sand.	150	Gas at Bethany and Webs- ter. Oil at Homer, Haynesville, Smackover, and Stephens.
(11) Eagle Ford	Shale, calcareous and red in places. Sandy at bottom	600	Oil at Caddo and De Soto.
(12) Woodbine	Sandy, lignitiferous	150(?) Doubtfully present	Gas at Bethany (?)
Cretaceous, Commanche, (13) Washita group	Limestones and clays.	300(?)	Gas at Bethany
(14) Fredericksburg group	Limestone	50 to 100 (?)	
Trinity group, (15) Glen Rose	Limestone	100 (?)	Oil at Caddo (Pine Island)

producing sand. Twenty miles farther northeast at Homer, the Nacatoch is logged as a producing sand more than 100 feet thick, but this thickness contains many shale and lime partings.

The tabular comparison of the Nacatoch formation as known in the producing areas (Table II), shows its changes northeastward from Caddo to El Dorado.

It has been suggested that the marked difference between limestone, chalk, and shale on the one hand and producing sand on the other, shown so plainly in what appears to be wholly Nacatoch formation at Bellevue, be recognized by using the term "Washington sand" as a differentiation of the producing sand from the other part of the Nacatoch formation. However, if separate members are

TABLE II
COMPARATIVE SECTIONS OF THE NACATOCH FORMATION

CADDO PARISH, LOUISIANA	BELLEVUE, LOUISIANA	HOMER, LOUISIANA	EL DORADO, ARKANSAS
Dixie Oil Co., Dillon No. 7	La. Oil Refg., Bodcau Fee A-4	Gulf Refining Co., Langston No. 16	Cooper-Henderson,* Hammond No. 1
Depth	Depth	Depth	Depth
Gas rock.....1,032-58	Chalk and lime, either Arkadelphia or Nacatoch. 228-260	Lime rock. 1,195-1,205	Lime and shale. 2,111-17
Gumbo.....1,070	Sandy shale, oil and gas show.....285	Packed sand.....1,224	Gumbo.....2,137
Gas rock.....1,109	Chalk rock.....290	Lime rock.....1,230	Broken rock.....2,140
Packed sand.....1,149	Shale.....308	Broken formation (oil sand).....1,321	Sand.....2,148
Gas rock.....1,168	Shale.....318		Broken rock.....2,150
Shale.....1,180	Broken formation (producing sand). 336		Sand.....2,160
Gas rock.....1,221			Rock.....2,164
			Sand.....2,170
			Shale and boulders. 2,184
			Gumbo and shale. 2,287
			Shale and lime.....2,301

* Correlation of this well by U. S. Geol. Survey, Press Notice, April 22, 1922.

to be distinguished in this formation, it seems preferable to the writer to retain the term "Nacatoch" for the sandy productive member in consideration of the fact that Veatch,¹ has already restricted that term to the sandy beds as differentiated from Hill's "Washington greensand" formation, and further because his term "Nacatoch" is already widely known as the actually producing sand.

The exact contact of the top of the Nacatoch formation with the bottom of the Arkadelphia clay is in many places difficult to determine unless a cap rock or an abrupt change to limestone or sand is present, for the bottom of the Arkadelphia is chalky and the top of the Nacatoch is limy and the method of drilling does not

¹ Veatch, *op. cit.*, p. 27.

always permit of distinction. Further, fossil evidence is not always conclusive, as the *Exogyra costata* zone of the Navarro formation of Texas extends above the Nacatoch sand.¹

The Annona chalk seems to be readily recognizable on the Sabine uplift, 300 to 400 feet below the top of the Nacatoch, and is productive at depths of 1,500 to 1,700 feet. It is about 300 to 600 feet thick and is easily distinguished in well logs by its position midway between the Nacatoch above and the Blossom below, the Nacatoch being separated from the Annona by the Marlbrook marl, and the Blossom being separated from the Annona by the Brownstown marl.

At El Dorado, Arkansas, however, about 80 miles northeast of the Sabine uplift and parallel to the strike of the formations, the Annona tongue of the Austin chalk is so poorly developed as a chalk that it may be absent or else represented by calcareous clays.²

At Monroe, Morehouse Parish, Louisiana, the largest known gas field in the world has its producing reservoir in a formation which seems to occupy a stratigraphic position similar to that of the Nacatoch, though its chalky character and lack of sand suggest the Annona. It is also logged as "gas rock."

The Blossom sand is 700 to 850 feet lower than the top of the Nacatoch formation. It is very similar to the Nacatoch sand in that it is a gray, glauconitic, quartz sand with light gray to white calcareous cement. It is a distinct sand, more than 100 feet thick, at the top of what is sometimes known in this territory as the Bingen group. It lies beneath the Brownstown marl and above the Eagle Ford clay.

The Eagle Ford clay and the Woodbine sand may be described together as there has been some uncertainty about their identification in the producing fields. The Eagle Ford clay may include as much as 600 feet of limy shales and clays between the Blossom sand above and the Woodbine sand below. These three forma-

¹ L. W. Stephenson, A Contribution to the Geology of northeastern Texas and southern Oklahoma. *U. S. Geol. Survey*, Prof. Paper 120-H. See Pl. XXX, opp. p. 155, 1918.

² *U. S. Geol. Survey*, Press Notice, April 22, 1922.

tions, Blossom, Eagle Ford, and Woodbine, have been grouped together as the Bingen sand¹ in southwestern Arkansas, where, at White Cliffs, Little River County, the Eagle Ford clays have pinched out and the Woodbine and Blossom combined to make an equal thickness of so-called Bingen sand. In the producing fields, however, both Blossom sand and Eagle Ford clay are generally recognized, and the Woodbine sand, though originally considered the producing formation below the Blossom at Caddo² is now considered as only doubtfully present in some fields,³ and at any rate not productive at Caddo and De Soto-Red River, production at these places coming from the lower part of the Eagle Ford.⁴

The identification of the Eagle Ford as the principal producer at Caddo and De Soto-Red River was made by Matson, Hopkins, and Stephenson in 1917, both on fossils⁵ and on lithological evidence. Since that time, local geologists have found Upper Washita (Lower Cretaceous) fossils in the De Soto field from a depth of 2,687 feet in the Autrey *et al.*, Bice No. 1 well. Lithologic correlation of the logs also indicates that this production is coming from a formation about 50 feet lower stratigraphically than the producing Eagle Ford, so that here is a strong suggestion of a new producing formation in the Lower Cretaceous.⁶

The Woodbine sand, therefore, has lost much of its former good standing in Louisiana and Arkansas. It is not the producing sand so commonly thought of on the Sabine uplift. It is still known, nevertheless, as a producing sand at Bethany, and in spite of the strong suggestion⁷ that it is absent at El Dorado, Arkansas,

¹ Veatch, *op. cit.*, pp. 23, 24.

² G. C. Matson, "The Caddo Oil and Gas Field, Louisiana and Texas," *U. S. Geol. Survey, Bull.* 619, pp. 48-49, 1916.

³ "Wildcat Wells in South Central Arkansas Stop Short of Deep Oil Sands," *U. S. Geol. Survey, Press Notice*, April 22, 1922.

⁴ G. C. Matson, and O. B. Hopkins, "The De Soto-Red River Oil and Gas Field, Louisiana," *U. S. Geol. Survey, Bull.* 661-C, p. 116, 1917.

⁵ Matson and Hopkins, *op. cit.*, pp. 114-16.

⁶ Information from F. X. Bostick, Standard Oil Company of Louisiana, A. F. Crider, Dixie Oil Company, and W. C. Spooner, Arkansas Natural Gas Company, Shreveport, Louisiana, 1923.

⁷ *U. S. Geol. Survey, Press Notice*, April 22, 1922.

there is some evidence to the contrary, for in the Standard Oil Company's Hill No. 1 well in sec. 1, T. 18 S., R. 16 W., a 50-foot sand containing lignite is overlain by Eagle Ford shale identified by fossils¹ and underlain by red shales.

The Glen Rose formation of the Trinity group is the only well recognized Lower Cretaceous formation that produces oil in this territory. It is sometimes known locally as the Trinity, or Pine Island Deep, as it was discovered in the Pine Island part of the Caddo field at a depth of about 2,900 feet, considerably deeper than any previous production. The producing formation is a fossiliferous limestone associated with beds of massive anhydrite. The overlying limestones and shales belong to the Fredericksburg and Washita groups as recognized by their fossil content. The Glen Rose limestone was identified by T. W. Stanton² of the U.S. Geological Survey and J. A. Udden² and others of the Texas Geological Survey from cores of the Louisiana Oil Refining Corporation's Ardis and Lay Well No. 1, in sec. 1, T. 21 N., R. 15 W. The discovery well in the Glen Rose formation was the Dixie Oil Company's Dillon No. 29, in the latter part of 1920, at a depth of 2,889 feet in sec. 14, T. 21 N., R. 15 W.

It is hoped that the systematic paleontological and microscopic work now being inaugurated by a few of the larger oil producing companies will be continued, and that, in keeping with their increasingly liberal-minded policy in regard to geological research and in the absence of comprehensive and sustained State and Federal work, the results will become available to the geological profession as a whole.

March 22, 1923

DISCUSSION

CHESTER WASHBURNE: What lies below the Glen Rose formation?

J. P. D. HULL: Possibly some other formation of the Trinity group, though so far as I know, considering the Glen Rose formation the bottom of the Trinity group, the next lower would be the so-called Basement Sands, or Paleozoic.

¹ Identified by F. X. Bostick, Paleontologist, Standard Oil Company of Louisiana, 1923.

² Personal Communication, 1921.

G. I. ADAMS: Have you observed green sands (glauconitic) to be of importance in the problem of oil accumulation either as a source or as a reservoir?

J. P. D. HULL: As a source, I have not; as a reservoir, yes. Glauconitic sand is a very noticeable constituent of both Nacatoch and Blossom producing sands, but it is also common in overlying and barren Eocene formations. In the producing sands, the glauconite appears to be in particles or grains similar in size to the quartz grains of the sand.

DIFFERENTIAL COMPACTING THE CAUSE OF CERTAIN CLAIBORNE DIPS

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Most geologists who have done work in the North Louisiana-South Arkansas district agree that the dips of the true bedding planes of the Eocene clays, and particularly those of the Upper Claiborne or Cockfield, more lately included in the Yegua, are by no means universally expressive of Cretaceous structure. These dips are most confusing and misleading both in their direction and their amount. The areas north and east of Stephens, Ouachita County, Arkansas; north of Atlanta, Arkansas; west of Bernice, Claiborne Parish, Louisiana; the southwest part of T. 16 S., R. 15 W., Union County, Arkansas, the Grambling area; and the southeast quarter of T. 22 N., R. 6 W., La.; and the southeast quarter of T. 19 N., R. 3 W., La.; all indicate anticlinal structure from the surface dips, but drilling has proved either a normal or synclinal condition. At numerous other places wells favorably situated with respect to only one or two reversed surface dips have revealed either normal conditions or synclines. Wells so located are the Pendleton well in Sec. 36, T. 18 S., R. 14 W., Union County, Arkansas; the Gulf Refining Company's Nickles well in Sec. 32, T. 23 N., R. 3 W., La.; the Texas Company's well in Sec. 2, T. 22 N., R. 2 E., Union Parish, Louisiana; and many others.

The dips may range from a degree or two to 20 or more degrees, even in short distances, and the direction of the dip may change even within the length of a single exposure extending not more than a few hundred feet. These dips generally appear to represent true bedding planes, and are quite different from cross-bedding dips and dips due to other depositional causes which occur throughout the Eocene formations in both the sand and clay phases. There has been considerable hesitation in concluding that surface Eocene

dips are not a reliable indication of subsurface structure, for they afford practically the only surface information over large areas. However, it is questionable whether geologists are justified in drawing even conservative conclusions from such data, even though they are unable to find better. Dozens and dozens of dry holes have been located by reputable geologists solely on the evidence of surface dips, and areas which have since proved productive have been condemned by equally reputable geologists because of the lack of so-called favorable dip evidence. It is believed that much unfavorable criticism of the geological profession might be avoided if we all frankly acknowledged the inadequacy of these dips, in themselves, as a basis for important geological conclusions.

This paper attempts to explain these confusing dips as phenomena due to differential compacting. It is generally recognized by geologists that after sediments have been deposited and much of the water drained from them, shrinkage occurs, and consequently in proportion to the amount of compactible sediments which are present, the thickness of a rock series will be reduced. For example a pure clay may be reduced by compacting 35 to 60 per cent, or even more. In the particular case of a bond clay from Bavaria, Bleining¹ found that the shrinkage water volume was 65 per cent of the true clay volume. Very little experimental work has been done in this direction. Blackwelder,² on calculations based on reasonable assumptions, concluded that the shrinkage due to compacting amounted to about 2 per cent in sands, 5 per cent in limestones, and from 15 to 35 per cent in shales. Blackwelder has also suggested that certain gently sloping domes in central Kansas and northern Oklahoma may be due to differential settling induced by the weight of overlying sediments on the underlying sediments which contain different proportions of sand and clay. Monnett³ has shown that the gentle folds of the North Mid-Continent field may possibly be accounted for by the differential settling of the sediments making up these folds. A comparative study of the well logs on the Garber structure shows that the wells

¹ *Trans. Am. Elect.-Chem. Soc.*, 1911.

² E. Blackwelder, *Bull. Am. Assoc. Pet. Geol.*, Vol. IV, p. 89, 1920.

³ V. E. Monnett, *Economic Geology*, Vol. XVII, p. 194, 1922.

located near the top or center of the fold penetrated a greater total thickness of sand than did the wells down on the flanks.

Where sand and clay are deposited in juxtaposition in the same horizon the resulting differential compacting will reduce the clay surface below that of the adjoining sand so that there will be a sloping surface dipping in toward the clay and away from the sand (Figs. 1 and 2). The application of differential compacting in the South Arkansas-North Louisiana territory is concerned with very local manifestations in certain horizons in the Claiborne and Wilcox. The Claiborne group consists of the Upper Claiborne, or Cockfield, which is entirely non-marine and is the surface formation over a large part of Columbia, Union, and Ouachita counties, and parts

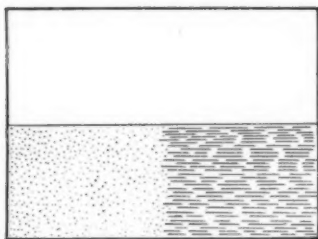


FIG. 1

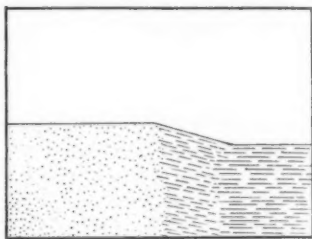


FIG. 2

FIG. 1.—Ideal section showing abrupt transition from sand to clay.

FIG. 2.—Ideal section showing resultant sharp dip after compacting.

of adjoining counties in Arkansas, and the Claiborne, or St. Maurice, which is partly marine, and covers a large part of the northern tier of Louisiana parishes as well as a belt north of the Cockfield outcrop in southern Arkansas. The dips in the Cockfield are most confusing and variable. The marine phases of the St. Maurice contain abundant fossils and the strata are fairly regular laterally. The dips are generally low, from one to two degrees, and much more uniform than in the Cockfield, and are, therefore, more expressive of the sub-surface structure. Where high dips are found in the marine St. Maurice it is generally discovered that they correspond with steeply dipping Cretaceous structures; for example the Arcadia, Bashaway, and other salt domes in Bienville and Webster parishes, Louisiana.

The Cockfield is made up of chocolate-colored or gray clay, and large amounts of gray to brown sand. Numerous well-preserved leaf impressions, as well as considerable lignite and other vegetable matter, occur throughout both the sand and clay. The sand may occur in the Cockfield as thin layers between much thicker clay layers; as grains admixed with the clay; or as massive deposits containing only a few widely separated and thinly laminated clay layers. Lenses of clay of varying size are irregularly distributed throughout the sandy phases, and similar lenses of sand occur through the clayey phases. The transitions from sand to clay may be very numerous and are often very abrupt; in fact, the most striking characteristic of the Cockfield revealed by a study of its exposures is its extreme lateral variability.

These field aspects of the Cockfield readily suggest its origin. It was probably deposited over a slowly subsiding, swampy area dotted with numerous small, irregularly-shaped lakes or lagoons ranging from a quarter of a mile to two or three miles in diameter. These lakes were probably intercommunicating and fed by numerous streams bringing in sand as well as clay in varying proportions. Ordinarily the sand would be deposited in the lakes near the stream mouths in irregular bars, and the clay would be deposited in the central and deeper parts. During flood periods the sand might be brought down in such quantities and with sufficient force to be laid down over almost the entire area of a lake. Naturally very irregular relations should arise between the sand and clay bodies in each lake and between the sand and clay bodies of different lakes. Gradation from one phase to another should be frequent and in some cases quite rapid. As the water was forced out of the sediments after, and, to some extent, during deposition, they should be compacted in proportion to their amount of clay and should consequently settle. The clayey portions should be reduced to a much smaller volume, and hence to a lower level, than the sandy portions, although originally they both may have been at practically the same level. The clay strata in order to accommodate themselves to their lowered level should bend down against the sandy phases where the sandy and clayey phases were in contact (Figs. 3 and 4). The strata of the more sandy portions, or those portions

that were constant laterally in their sand-clay proportion, should retain practically their original plane of deposition. Accordingly, a number of sloping surfaces should produce dips in toward the clayey parts and outward away from the sandy parts, which should be irregularly distributed depending on the number of sand-to-clay transitions. The magnitude of the dips should depend on the abruptness of the transition. For example, if in going lakeward from a stream-mouth sand bar there was originally a deposit of 30 feet of sand which merged into approximately the same thickness of clay, after compacting the sand would be reduced to about 29 feet and the clay to 24 feet. The resulting difference of 5 feet would

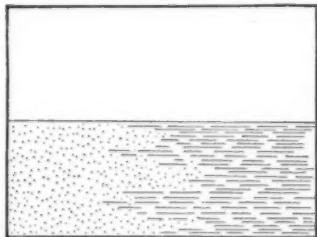


FIG. 3

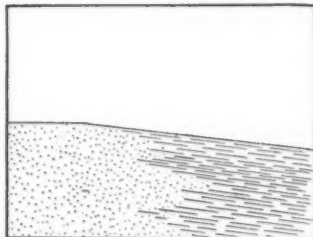


FIG. 4

FIG. 3.—Gradual transition from sand to clay.

FIG. 4.—Resultant gradual dip after compacting.

be taken up in a slope from the sand to the clay (Figs. 1 and 2). If the contact between the sand and clay was sharp, say within a distance of 50 feet the resulting slope would be about 10 degrees; but if the transition was gradual, say from 300 to 500 feet, the resulting dip would be only 1 or 2 degrees (Figs. 3 and 4). Variations in sand and clay content should, of course, give rise to an infinite number of modifications of this assumed ideal case (Figs. 5 and 6). In this manner many of the irregular and confusing dips in the Cockfield formation, and in any other non-marine formation where there is considerable lateral variation, may have been produced.

It might appear that a criterion as to the tenability of this idea relates to the sandy centers and flanks for the dip anticlines and

domes. The Cockfield dips should slope toward the clayey phases and away from the sandy phases. In general, field observations show that this is the case. However, in application of the test care must be used to distinguish between Quaternary and Eocene sand, and it must be remembered that the difference in sand content sufficient to produce dips by differential compacting may not be striking.

A good example of dips inferred to have been caused by differential compacting may be seen in a cut on the Vicksburg, Shreveport & Pacific Railroad a mile east of Grambling, in Lincoln Parish, Louisiana. Here, almost directly abutting massive sand, which is probably

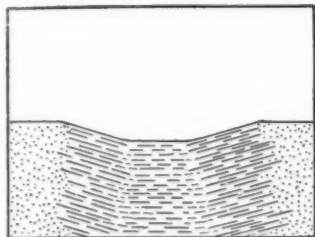


FIG. 5

FIG. 5.—Section showing differential compacting resulting in apparent synclinal dips.

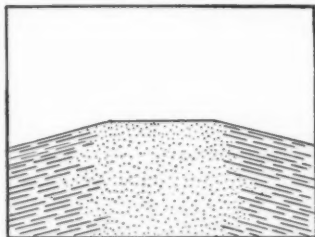


FIG. 6

FIG. 6.—Section showing differential compacting resulting in apparent anticlinal dips.

of Claiborne age, well-stratified clay dips eastward from the sand at an angle of 14 degrees. Within 50 feet to the east this dip has flattened to 1 degree in the same direction. Other less apparent examples, in which the sandy and clayey phases are from several hundred yards to a half mile apart and without intervening exposures, are numerous. Perhaps the most striking case occurs on Little Cornie Creek in Columbia County, Arkansas, in the northwest quarter of Sec. 5, T. 20 N., R. 18 W. Here are two exposures of massive Cockfield sand, one 14 feet thick, just above the Three Creeks-Gordon Road bridge over the Little Cornie, and the other 9 feet thick, a quarter of a mile farther up the creek. In a field gulley, 500 yards north of these exposures, 30 feet or more of

chocolate-colored clay at the same elevation as the sand shows a general northwest dip of about 2 degrees. In several cases quaquaversal clay dips point away from a central area with predominant sand at the same horizon as the clay. Examples of this occur in Sec. 29, T. 17 N., R. 18 W., Columbia County, Arkansas; the area of the Grambling structure centered a little west of Grambling in Lincoln Parish, Louisiana; and one to three miles north of Atlanta, centering about Sec. 22, T. 18 N., R. 19 W., Columbia County, Arkansas; and the area north of New London, in eastern Union County, Arkansas.

Whether the Haynesville district, which is so frequently designated as an example of the reliability of surface dips, shows a coincidence of surface and subsurface dips is uncertain. In passing it may be said that the surface formations at Haynesville generally consist of a sandy clay which is fairly constant laterally, and that at least one of the north dips, that on the Emerson road 4 miles north of Haynesville, consisting of sand and sandy clay, dips toward an extremely clayey phase at and below the same elevation a few hundred yards north.

Of course, some of the dips in the Cockfield clay must be due to structure, although it is unlikely that very many of them could have persisted without change through the zone of extremely high and variable dips due to differential compacting. No method for the distinction in isolated exposures, between dips due to structure and those due to compacting, is now known. It is probable that some of the dips associated with one or two well-defined faults in the southern Arkansas region are due to deformation.

Dips in that part of a uniform clay phase at some distance from a sand contact should be fairly reliable. Dips in the sandy phases of laterally variable sediments should be much more reliable than those in the clayey phases since the sand is not compacted nearly so much as the clay. In most cases, however, the sands are so cross-bedded or so massively bedded that the true bedding may hardly be distinguished. Therefore, in wildcat territory it is very doubtful whether Cockfield dips or any dips in laterally variable sediments are of much value as clues to the subsurface structure, but they are confusing and misleading. Not only are we

likely to be misled in assuming that quaquaversal dips represent sub-surface domal structure, but we are also in grave danger of misjudging the actual conditions if we assume that uniformly normal dips in laterally variable material represent sub-surface normal conditions. The transitions from sand to clay may be so arranged over an area that a series of local, apparently normal dips are produced from differential compacting, and deformative forces which are not observable in the higher surface dips may have easily produced sub-surface folding. However, where the existence of Cretaceous folding has been established by some means other than surface dips, study of the surface dips may lead to satisfactory general conclusions regarding the size and trend of the fold beneath.

Of course, the application of the principle of differential compacting need not be restricted to the Cockfield, but it can be applied wherever the sediments show lateral variability, as is the case in some horizons in the St. Maurice, and most certainly throughout the Wilcox. It is also possible that areas exist in the Cockfield where there is no lateral variation. It is, therefore, suggested that much more attention be paid to lateral variation in the Eocene sediments of southern Arkansas and northern Louisiana in order to determine whether in any area there is sufficient lateral variation to account for the local dips. If no lateral variation is found the local surface dips may be concluded to generally represent subsurface folding. It is desirable that the practical worthlessness from the standpoint of subsurface structure of these Eocene dips over large areas, be candidly admitted, and that our efforts be directed toward finding more dependable data before recommending or condemning an area. It is probable that significant results can be obtained in the correlation of surface stratigraphic horizons in laterally variable sediments by a microscopic study of samples from various exposures, with a view to identification of distinctive mineral grains, or, less probably, distinctive faunal or floral characteristics.

March 22, 1923

DISCUSSION

FRANK DEWOLF: The subject presented by Mr. Teas is of great importance, and I am hopeful that he may have some quantitative data from field or laboratory as to the amount of shrinkage in clays of various types, and the time during which the differential effects continued.

Those who have worked in the coal fields are aware of the unequal subsidence indicated by variations in thickness of a coal bed. If the bed is three or four feet thicker than normal in one area, implying a difference of perhaps 50 to 90 feet in original vegetable matter, the greater shrinkage in the thick material would tend to perpetuate a basin there and overlying clastics would have an apparent dip into the basin which can be expressed quantitatively in terms of thickness of coal or of original peat. Attention may be called to studies by G. H. Cady for the State Geological Survey of Illinois, and published in *Co-operative Mining Investigations Bulletin 15*, in which the data and conclusions relating to such a basin are presented. It is further shown that the basin condition did not finally disappear until overlying beds perhaps 200 feet thick had had time to accumulate. Then a higher thin coal was laid down horizontally with even thickness.

R. F. SCHOOLFIELD: I would like to suggest the hypothesis of "surface crumpling" to account for many of the false dips in the soft Tertiary formations of Arkansas and Louisiana. In southern Arkansas several exposures of lignitic shale beds are to be seen, varying from 10 to 100 feet in length, in which the dip of the beds is reversed from 2 to 8 degrees in one direction to as great an inclination in the opposite direction—these small folds being usually asymmetrical, however. If there is reason to suspect lateral compression in a region, it seems very reasonable to believe that clay beds, 50 to several hundred feet below the surface and weighted down with the overlying sediments, would in many cases take up the lateral stress by compacting, whereas beds near the surface would be occasionally thrown into small folds as I observed.

RELATION OF UPPER CRETACEOUS TO EOCENE STRUCTURES IN LOUISIANA AND ARKANSAS

A. F. CRIDER
Shreveport, Louisiana

INTRODUCTION

In a discussion of most geologic subjects three factors are of vital importance: observation, experiment, and reflection. With these as his guide the geologist is led into contact with facts from which conclusions are reached and theories are advanced to explain and harmonize the laws of nature. Frequently the facts on a given subject are very fragmentary, and additional evidence is needed in order to reach correct conclusions. In a study of the relation of Upper Cretaceous to Eocene structures the above mentioned factors play an important part.

BASES FOR DETERMINING STRUCTURE

The presence of Cretaceous folding in Louisiana and Arkansas can be determined only by a study of well logs. The presence of Eocene folding may be determined in two ways: (1) by the correlation of well logs on one of three horizons, the Queen City sand, the St. Maurice and the base of the Midway, and (2) by surface outcrops.

WELL LOG DATA

Queen City sand.—Where logs have been accurately kept, the most dependable horizon in the Eocene, is the base of the 600-foot sand in the Haynesville field. This sand occurs at about the base of the Claiborne, and is perhaps the equivalent of the Queen City bed in Texas. It marks a well-defined fresh-water horizon in the Smackover and Haynesville fields and throughout northern Louisiana and southern Arkansas, where it is below the surface.

St. Maurice.—Another horizon for correlation work is the top of the St. Maurice. This can be determined only by fossil evidence and is therefore to be used only where samples of cuttings or cores from wells have been kept.

Midway.—Still another horizon is the base of the Midway which can be used as a general check in correlation work.

SURFACE OUTCROPS

The question of whether folding in the Upper Cretaceous, which can be determined only by logs of wells, is reflected in Eocene surface outcrops is one which could be answered in the affirmative if two things could be established: (1) that the force which bent the Cretaceous strata into folds was exerted after the deposition of the Eocene, and (2) that no major erosional unconformities are present within the Eocene or at the contact between the Eocene and the Cretaceous.

UNCONFORMITIES

There are numerous references in geologic literature, of the Gulf Coastal region, to unconformities at the Cretaceous-Eocene contact and at the Midway-Wilcox contact. Were either of these a pronounced erosional unconformity it would affect the structural conditions in these and in younger formations. Interruption in deposition is proved by the sudden break in the faunal and floral life. E. T. Dumble¹ states that there is much evidence of emergence and erosion between the Wilcox and the Claiborne in southwestern Texas. Reference to an erosional unconformity between the Wilcox and the Claiborne, in western Georgia, is made by Veatch and Stephenson.² E. W. Berry³ states that "from numerous well logs recently collected by Matson and Hopkins in the Naborton oil field of Louisiana, it is obvious that the lower and most, if not all, of the middle Wilcox are completely transgressed by the upper Wilcox."

So far as shown by the evidence of well logs in closely drilled areas like Homer, Haynesville, and Eldorado, the break in continuity of the strata across the above mentioned unconformities in northern Louisiana and southern Arkansas is of such small importance, if indeed, it is present at all, that it is not possible to detect greater difference between a fold contoured on some horizon in the Upper Cretaceous and one contoured on some horizon in the

¹ *Jour. Geol.*, Vol. XXIII, 1915.

² *U. S. Geol. Survey*, Prof. Paper 99.

³ *U. S. Geol. Survey*, Prof. Paper 95, p. 78.

Claiborne, than would result from inaccuracies and measurements in rotary-made logs. The constance of the interval between the base of the 600-foot Claiborne sand and the base of the Annona chalk producing horizon in the Haynesville field is most striking. Even allowing for the variation of rotary-made logs, the interval in a large number of logs varies less than 20 feet. This interval is so uniform that if any great erosional unconformities between the producing sand and the middle of the Claiborne, were present they could be detected in the logs. The well logs in this region show a uniformity of interval from the upper Cretaceous to the top of the Claiborne, and the unconformities are so slight that well logs show the same amount of structural deformation in the Claiborne as in the Upper Cretaceous. Therefore, the force which produced the deformation must have taken place at least after the deposition of the Claiborne.

There is evidence in the Pine Island field of a pronounced erosional unconformity near the close of Lower Cretaceous time. Cumulative evidence points to the fact that this hiatus is extensive in southern Arkansas and northern Louisiana. Other major unconformities are probably present in the Lower Cretaceous, with old folds and depressions which may be reflected in the Upper Cretaceous.

There may have been slight crustal movements in Upper Cretaceous time previous to the deposition of the Wilcox, but the evidence from well logs and from surface folding points conclusively to the fact that the major folding in the Upper Cretaceous took place later than Cockfield.

VALUE OF SURFACE WORK

If Upper Cretaceous folding, which has produced as much as 100 feet closure in some of the fields, is reflected in the Wilcox and the Claiborne why should not surface work be dependable? Research based on paleontology and lithology is surely just as effective in the Gulf Coastal region as in Oklahoma, Wyoming, or West Virginia.

Surface dips are present in Louisiana and Arkansas, and they mean just as much here as they do in a hard-rock district, but the

complex of cross-bedding and differential settling is so confusing that only the novice and the veteran will venture an opinion as to their significance. Dips should be used as corroborative evidence only. Haynesville, Homer, Arcadia, and Smackover have been beautifully outlined by surface dips after these fields have been developed, but only a few of the geologists ventured an opinion on the significance of these dips before the fields were drilled. The fact that some of these fields were outlined before drilling was commenced proves the value of competent geological surface investigation.

By study of surface dips, assisted by fossil and lithologic evidence, the Arcadia salt dome, Haynesville, Homer, and the salt dome in sec. 16, T. 17 N., R. 8 W., were discovered previous to being drilled. That Smackover and the shallow Bossier fields were possible structural highs, was indicated by Veatch in Professional Paper 46. In the Homer field the Wilcox strata have been pushed through younger strata forming a rim of St. Maurice around Wilcox. In the shallow Bossier field the surface formation is the Arkadeiphia with concentric rings of younger formations.

Not all surface dips are due to folding and not all Cretaceous folds can be worked out by surface investigation owing to the surficial covering which, in some of the fields, has completely obliterated traces of folding. However, this does not lessen the fact that the folds are present and drilling proves that these surface folds continue downward into the Upper Cretaceous and perhaps below it.

Question may be raised as to the occurrence of well-defined closed structures in the Wilcox or Claiborne which are not continuous into the Cretaceous. The writer's answer to this question is determined by opinion, based on personal observation. So-called "surface structures," which when drilled show no folding on the Nacatoch, will likewise show no folding in the water sand in the Claiborne.

DISCUSSION

K. C. HEALD: To what extent are folds as outlined by surface dips exactly superposed over structures in deeper sands? In the Pennsylvanian rocks of Oklahoma comparison of the surface structure with that of the oil sand appears to show that the axes of domes or anticlines may be inclined as much as 45° in spite of the gentle nature of the folds which have maximum dips of less than 300 feet to the mile. An explanation that has been tentatively advanced is

that the inclination of the axis is due to lateral movement along faults in basement rocks which introduced a horizontal component into the forces that produced the uplift.

N. F. DRAKE: In working over Cleveland County, Arkansas, and parts of adjoining counties I have found that two systems of folding and faulting are shown there in surface exposures. One system of folds and fault lines runs about S. 65° W. by N. 65° E. while the other system runs about N. 20° W. by S. 20° E.

Toward the east end of the observed N. 65° E. by S. 65° W. line of faulting a vertical displacement of about three feet of normal faulting is shown while some ten or twelve miles to the west on this same belt or line of faulting thrust faulting is shown. Similarly on a line of the N. 20 W. by S. 20 E. folding and faulting near the south end normal faulting is shown while eight or ten miles to the north on this fault line, thrust faulting is shown.

Both systems of faulting are accompanied by parallel lines of folding shown by dips of outcropping strata. The dips in general "line up" in such order as to give them reliability, and furthermore they check with the lines of faulting.

A. F. CRIDER: Sufficient amount of detailed investigation has not been made to answer Mr. K. C. Heald's question. However, it is known that the amount of divergence in the surface and Cretaceous folds varies in the different fields. In Haynesville, where there is perhaps a minimum amount of faulting, the axis of the fold contoured on the 600 foot sand practically coincides with the axis of the fold contoured on the producing horizon.

In the Homer Field, where the faulting plays an important part in the structure there is a greater amount of divergence in the folds of the basement rocks than in those of the surface. This would tend to strengthen the explanation advanced by Mr. Heald.

GEOLOGY AND STRUCTURE OF PORTIONS OF GRAND AND SAN JUAN COUNTIES, UTAH

H. W. C. PROMMEL
Denver, Colorado

INTRODUCTION

The area discussed in this paper is situated in the south-central part of Grand County and the northern part of San Juan County, Utah. It comprises a block of approximately 500 square miles trending in a northwest-southeast direction along the Thompsons-to-Moab stage road as far as Moab, thence down Colorado River to its junction with Indian Creek. The area lies to the south of Thompsons, a station on the Denver & Rio Grande Railroad.

The field work was done during the summers of 1920 and 1921. The writer was accompanied in the field by K. B. Nowels and R. F. White during 1920 and by H. E. Crum, who was in charge of the field work a part of the time, A. J. Hazlewood, and E. E. Johnson during 1921. Special credit is due these gentlemen for their hearty co-operation in the work. Messrs. C. A. Fisher and H. W. Lowrie, Jr., of the engineering firm of Fisher & Lowrie, have contributed largely to this paper by advice and helpful criticism.

The climate is that of the arid plateau regions west of the Rocky Mountains, with extreme heat during the summer and comparatively low temperatures during the winter.

The topography of the Moab region is that of the high plateaus west of the Rocky Mountains. The region is dissected, however, by numerous steep canyons and draws. As a rule the anticlines in the northern part of the region here discussed are extensively faulted along the axes, and valleys from one to three miles wide have been formed along these lines of weakness in the formations. These valleys are surrounded by hills with precipitous slopes and cliffs on the valley side while to the northeast and southwest away from the valleys they form long dip slopes dissected by narrow canyons cut into the soft sandstone by the run-off. The massive

sandstones near the top of these hills are carved into columns, alcoves, and natural bridges by wind erosion. On the outer edges of the dip slopes there are lines of hogback hills formed by more resistant formations. Still farther to the northeast and southwest, where the Mancos shale covers the surface, the topography changes to that of a nearly featureless plain (Fig. 1).

GEOLOGY

The rocks covering the surface of the area range from the Hermosa formation of Pennsylvanian age to the Mancos shale of Cretaceous age and make up a stratigraphic column over 5,000 feet thick in which not less than seven and probably more unconformities are present.

The Pennsylvanian can be divided here into two parts which closely correspond to the Hermosa and Rico formations as described by Cross and Ransome,¹ who assign the lower fossil-bearing red beds which are present in southwestern Colorado, known as the Rico formation, to the Permo-Pennsylvanian.

Cross and Ransome divide the Hermosa into three parts; the lowest, with a thickness of approximately 800 feet, consists of shales and impure limestones at the base, green or gray grits or sandstones alternating with gray shales and containing several beds of black shale and thin impure limestones near the middle, and massive and flaggy sandstones at the top. A bed of rock gypsum is present near the middle of this lower division. The medial division of the Hermosa consists in the main of blue massive limestone in beds 5 to 100 feet thick separated by shales and sandy shales. It has a thickness of 600 feet, more or less, and is a prominent feature on account of its massive limestone series. The upper division, which is from 400 to 600 feet thick, consists of black and gray shales alternating with green grits and sandstones. Reddish sandstones were observed and black shales are present in the lower third of the division. The topmost member consists of some 30 feet of fine-grained, mica-bearing, green shales immediately above which comes the red, sandy, fossiliferous limestone of the Rico beds.

¹ Whitman Cross and F. L. Ransome, *U. S. Geol. Survey Geol. Atlas*, folio 130, Rico Quadrangle, Colo.

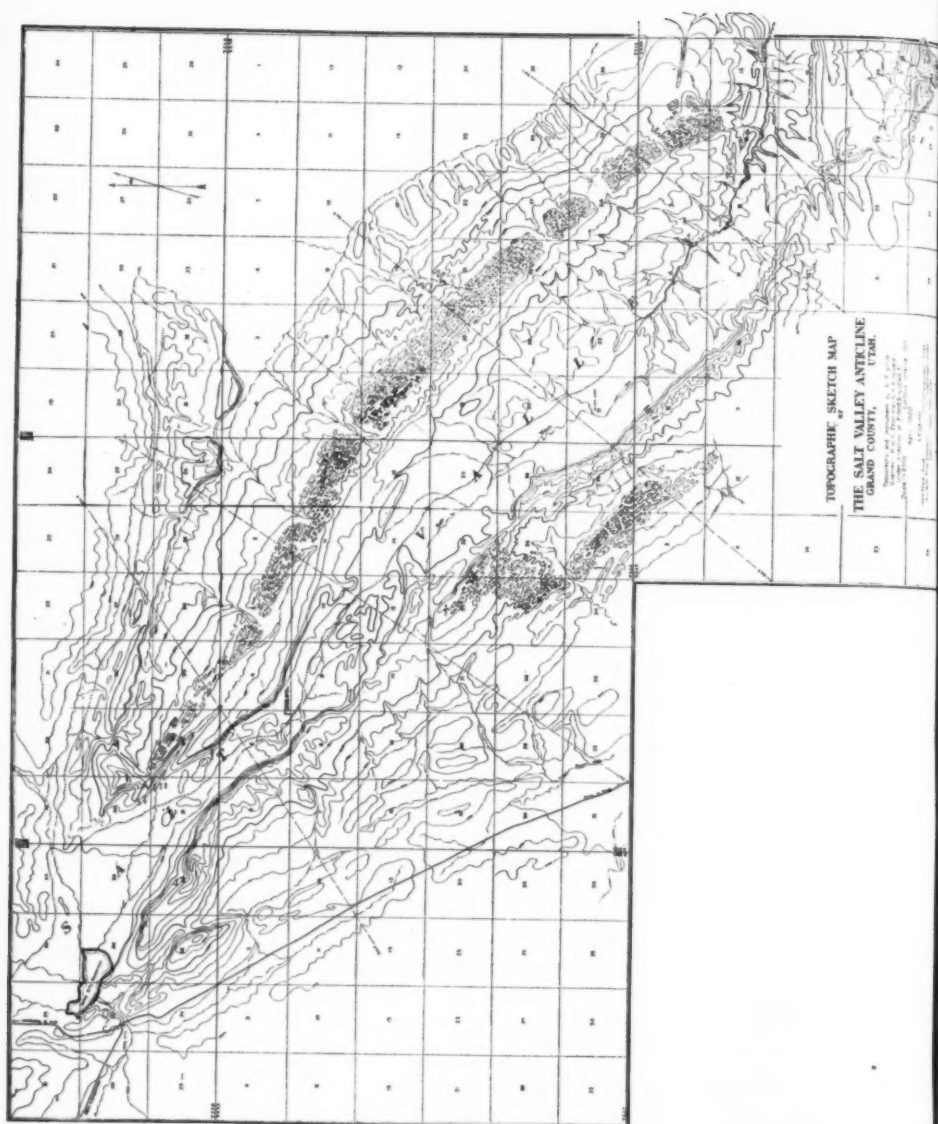


FIG. 1

GENERAL STRATIGRAPHY OF PORTIONS OF GRAND AND SAN JUAN COUNTIES, UTAH

System	Series or Group	Formation	Subdivisions	Thickness in Feet
CRETACEOUS		Lower Mancos shale with Ferron sandstone member Dakota sandstone and conglomerate		400 300
		McElmo formation	Marked Unconformity 1st McElmo sandstone 2d McElmo sandstone Variegated shale with petrified wood horizon Variegated shale, sandy near base 3d McElmo sandstone 4th McElmo sandstone Limestone and shale with flint horizon near base	300 400 100 100 300 1,000 ±
JURASSIC		Upper Navajo	White massive sandstone Pink massive sandstone	100 300
		Middle Navajo	Sandy red shale Light brown sandstone	Unconformity Unconformity 600
	La Plata group	Lower Navajo	Thin limestone Light brown sandstone	Unconformity 500
		Toddlito formation	Red shale and sandstone	
		Wingate sandstone	Red to purple sandstone	400-500
		Chinle formation	Red sandstone and shale	
		Shinarump Conglomerate	Unconformity	200
TRIASSIC			Marked Angular Unconformity Chocolate and purple sandstone and shale	515 200 ±
	PERMIAN	Monkapi-Culler	Red beds, conglomerates, sandstone and red shale	1,340-1,500 835-875
CARBONIFEROUS			Sandy limestone, red sandstone and shale	550
	PERMO-PENNSYLVANIAN	Rico formation	Gray, blue, green, and white limestone, sandstone and shale	280 2,000 ±
	PENNSYLVANIAN	Hermosa formation	Limestone, sandstone and shale, not exposed	1,700 ± Total 0,900-7,140

A description of the Rico formation by Cross and Ransome is as follows:

The general characteristics of the Rico formation in the vicinity of Rico are first, its calcareous nature in which it resembles the strata above and below; second, the feldspathic constitution and the coarseness of its sandstone, in which respect it differs from the Hermosa and resembles the Cutler; and third, its chocolate or dark maroon color which contrasts sharply with the gray or green of the Hermosa and which is more or less distinct from the bright vermillion of the Cutler and Dolores.

The Pennsylvanian in southeastern Utah, including the area here discussed, can also be divided into a red series above and a gray series below, corresponding in a general way to the Rico and Hermosa divisions of Cross and Ransome in Colorado. Woodruff¹ applies the name "Goodridge formation" to the Pennsylvanian series exposed at the Honaker Trail section in the San Juan oil field of southeastern Utah. The marked change from the red to the gray series, which was noticed by the writer in the Moab region, as well as in the San Juan oil field, the lateral inconsistency in the beds of the Hermosa—that is, the changes from limestone to shale and sandstone at the same approximate stratigraphic horizon on the sections of southeastern Utah—correspond so closely to Cross and Ransome's description of these beds in the Rico quadrangle that it is the writer's opinion that the Rico and Hermosa series of the Pennsylvanian extend from Colorado westward far into southeastern Utah, so that the Goodridge formation should be correlated with the Rico and Hermosa of Colorado rather than with the Kaibab of Arizona.

The classification of formations in this paper is based mainly on lithologic grounds. The writer fully recognizes the importance of classification on paleontologic evidence and considers it extremely regrettable that his time was too limited to make extensive fossil collections for paleontological study and closer classification of these beds.

The lower division and the greater part of the medial division of the Hermosa, approximately 1,700 to 2,000 feet in thickness, do not

¹ E. G. Woodruff, "Geology of the San Juan Oil Field, Utah," *U. S. Geol. Survey Bull.* 471.

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come to the surface in this region. It is estimated by the writer that approximately 280 feet of blue to gray limestones, sandstones and shales of the Hermosa formation are exposed at the surface at the apex of Colorado River structure No. 1 (Fig. 2).

The top of the Rico formation of this region was arbitrarily chosen at the uppermost limestone in the red beds section. In the Moab Canyon section this limestone is non-fossiliferous, and 4 feet in thickness. It is underlain by a series of sandstones, shales, grits, conglomerates, and occasional limestones, the last of which are more frequent toward the base of the series. The constituents of the sandstones and grits are mainly feldspathic and consist of angular and rounded granite and quartz pebbles. The prevailing color of the section in Moab Canyon is red and corresponds more or less to the section of the Rico formation measured on Colorado River structure No. 1 some eight miles southwest of the Moab Canyon locality. At the Rico section mentioned the uppermost limestone in the red beds is a sandy, spally, bluish, concretionary limestone, which is very fossiliferous. It is 5 to 20 feet thick. In Cane Springs Wash, about three miles east of this place it has the appearance of a bluish-purple shale rather than limestone, containing bands of nodular, sandy limestone. This limestone, however, is the most widely distributed formation over the area of Colorado River structures 1 to 4, as it was followed south over a distance of thirty miles. It was chosen as the key bed on which to draw structure contours of the Colorado River structures. Generally speaking, this limestone thins to the east and north but appears to thicken somewhat and is well developed toward the southwest and south.

The Rico formation is overlain by the Cutler-Moenkopi series of red beds, of Permian age (Plate III). The lower part of this series consists of red beds, conglomerates, sandstones, grits and red shales. The constituents of the conglomerates in the lower part are granitic pebbles. The lower portion of the Moenkopi-Cutler series resembles very closely the Cutler formation of Colorado while the upper part is very similar to the Moenkopi as described by Gregory.¹ The thickness of the entire series ranges from 1,300 to 1,400 feet.

¹H. E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey, Prof. Paper* 93.

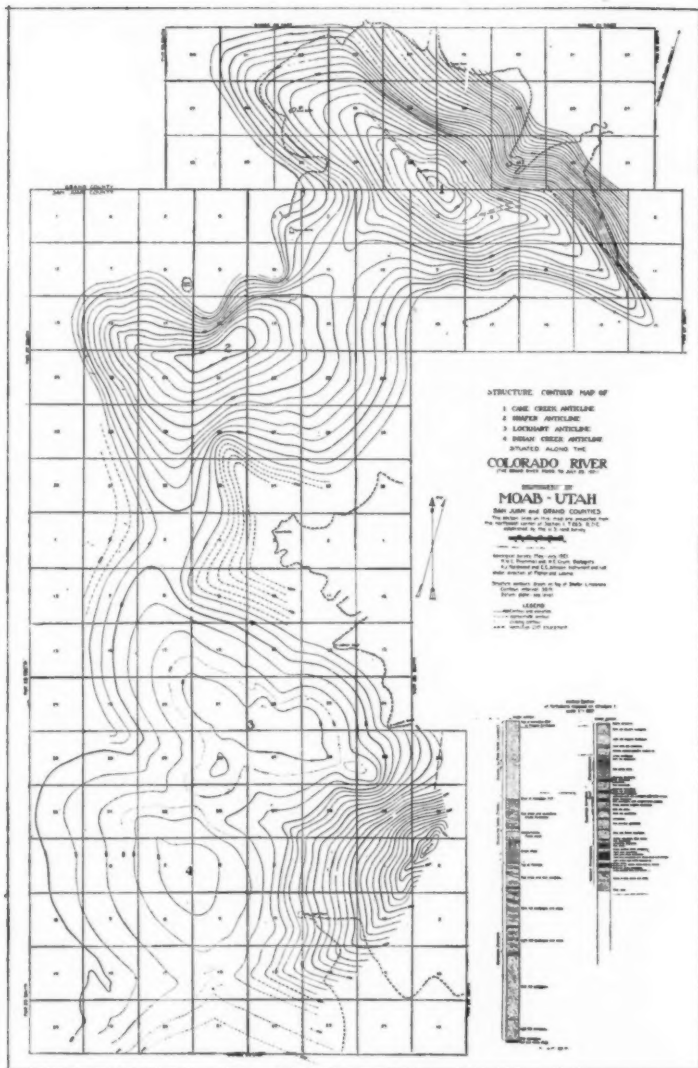


FIG. 2

At the top of the Moenkopi-Cutler in Moab Canyon there occurs a very marked angular unconformity. The Permian beds decrease rapidly in thickness to the southeast and increase rapidly in thickness to the northwest. At the section in Moab Canyon, near what is known as the "dugway," the beds between the Shinarump and the uppermost Pennsylvanian limestone are 779 feet thick. Two miles southeast they are only 187 feet thick and are underlain by a series of sandstones and limestones which may correspond to the lower part of the section taken in Moab Canyon near the "dugway." It is also possible that these limestones and sandstones are somewhat lower stratigraphically than those of the Moab Canyon section, the unconformity cutting out nearly all of the Permian and part of the Carboniferous beds. The Moab fault, however, obscures conditions and the beds are somewhat metamorphosed and even locally mineralized so that they cannot be correlated with certainty. Northwest of the Moab Canyon section the Permian beds increase in thickness from 779 to 1,211 feet in four miles. The marked angular unconformity at this stratigraphic horizon was noticed by Whitman Cross twelve miles up Colorado River from the Moab bridge.¹

The Permian beds are overlain by the Shinarump conglomerate series which is here approximately 200 feet thick and consists of extremely thin-bedded, fine-grained sandstones intermingled with irregularly distributed conglomerate. Toward the base of the series the conglomerates occur in beds of yellow to olive drab colors and are locally 6 to 10 feet thick. At the top of the Shinarump series another slight unconformity occurs.

The Chinle formation, consisting here of soft, purple sandstones alternating with layers of brown to red shales and sandstones irregularly bedded and cross-bedded, is about 200 feet thick. However, a marked unconformity occurs near its top. The sandstones overlying the Shinarump conglomerate increase in thickness to the southeast and diminish in thickness to the northwest. From the section in Moab Canyon at the "dugway" these sandstones increase from 250 to 301 feet in about three miles toward the southeast and diminish to less than 200 feet to the northwest.

¹ Whitman Cross, "Stratigraphic Results of a Reconnaissance in Western Colorado and Utah," *Jour. Geol.*, Vol. 15, No. 7, 1907, pp. 634-79.

The LaPlata group of the Jurassic has been divided from the bottom upward into the Wingate sandstone, Todilto formation, the Lower Navajo, Middle Navajo, and Upper Navajo.

The Wingate sandstone (formerly known as the Vermilion Cliff sandstone) consists of red to purple massive cross-bedded sandstones which usually stand out in bold cliffs. It is overlain by the Todilto formation consisting of red shales and sandstone somewhat thinner-bedded but in places hard to distinguish from the Wingate. The Todilto and Wingate together are 400 to 500 feet thick. The Lower Navajo (formerly known as the Lower LaPlata sandstone) consists of a massive brown sandstone 300 to 500 feet thick, showing few or no bedding-planes. It usually weathers into cliffs and its line of outcrop is hummocky. Near its top there is a slight erosional unconformity at which a thin limestone layer is found interbedded in the massive sandstone. This limestone is present on the Salt Valley anticline but was not studied at other localities. The limestone does not seem to be continuous but appears to have been laid down in depressions in the Lower Navajo sandstone. Above the Lower Navajo occurs a series of red, sandy shale ranging in thickness up to 200 feet. A very marked erosional unconformity at the top of this shale series is observed on the Salt Valley anticline, in the Moab Canyon section, and appears to extend as far south as Bluff, Utah. The red shales are overlain by the pink massive Upper Navajo sandstone, consisting of 300 feet of sandstones, showing no bedding-planes. This sandstone weathers into fantastic sheets, columns, alcoves, and natural bridges and forms a distinct division of the LaPlata group. A slight unconformity occurs at its top. In a few places it is overlain by from 8 to 10 feet of red and white banded shaly sand while in most places a white massive sandstone 50 to 100 feet thick directly overlies it and forms the top of the LaPlata group. The divisions of the LaPlata as described above are plainly visible on the flanks of the Salt Valley anticline; they can also be studied at Moab Canyon and vicinity and can still be discerned seventy miles south of Moab between the town of Bluff and the San Juan oil field. The total thickness of the LaPlata group in this region ranges from 1,300 to 1,400 feet. Geologic formations above the lower part of the Jurassic are present only on

the flanks of the Salt Valley anticline. They consist of the McElmo formation, which overlies the LaPlata group, and the Dakota-Lakota sandstone and Mancos shale of Cretaceous age. A very marked unconformity occurs between the Dakota-Lakota series and the McElmo formation. In places where the old land surface of the McElmo formation was elevated, the Dakota-Lakota series is entirely missing while in places where the McElmo was deeply eroded, the Dakota series rests on the shale occurring near the middle of the McElmo formation. The total thickness of the McElmo formation is 1,000 feet plus or minus, while that of the Dakota-Lakota series is approximately 200 feet. The lower Mancos shale from the Ferron sandstone downward is 400 feet in thickness.

STRUCTURE

The area discussed in this paper is situated on the east flank of a structural basin bordered by three groups of laccolithic mountains. They are the Henry Mountains seventy miles to the southwest, the Abajo or Blue Mountains fifty miles to the south, and the La Sal Mountains five to ten miles east of this area. Some of the sedimentary formations which still extend part way up the flanks were slightly arched by these laccoliths. The anticlines along the sides of the structural basin appear to have been formed, in part, by folding of the sedimentary formations caused by stresses and strains from the large laccolithic uplifts and in part by arching due to minor deep-seated laccoliths extending outward from the major groups. From exposures in Moab Canyon and the canyon of Colorado River, near the apex of structure No. 1, it is evident that the Pennsylvanian strata were involved in the folding.

A series of deep-seated continuous strike faults which show the greatest vertical displacement near the laccolithic mountains, and which die out away from them, occur in the northern part of this region. The trend of the major faults within this area is northwest-southeast. Vertical displacement of sedimentary formations along the faults and faulted zones range from almost 0 to 3,500 feet, the amount of faulting and amount of displacement diminishing very rapidly from Moab southwestward, so that on the Colorado River structures 1 to 4 no vertical displacement of more than 150 feet was

noticed along the faults on the east side of these structures. The deposition of secondary minerals of copper and silver along the larger faulted zones makes it apparent that they have been passage-ways for ascending or descending solutions. A network of secondary faults and faulted zones, along which no mineralization was noticed, is present in parts of the area under discussion. The anticlines trend in a northwest-southeast direction across the southern part of Grand County and the northern part of San Juan County. The northeasterly structure is the Salt Valley anticline (Plate III). It is separated from the Moab anticline by a broad structural trough known as the Courthouse syncline, on the southwest side of which the beds rise again to form the Moab anticline. From the crest of the faulted Moab anticline the beds dip gently to the southwest for a distance of three miles toward the axis of the Kings Bottom syncline from which they rise southwest toward the anticlinal axis of Colorado River structures 1, 2, 3, and 4. Colorado River structures 1 to 4 are not separated by deep synclines as is the case with the Moab and Salt Valley anticlines to the northeast in closer proximity to the La Sal Mountains. It appears that structure No. 1 is a flexure developed in connection with the Salt Valley and Moab anticlines. Colorado River structures 3 and 4 undoubtedly form minor closures along a pitching anticline, forming the north extension of the Blue and Elk mountains, while structure No. 2 is situated at the junction of these two lines of major folding. Structures 1 to 4 are separated only by narrow saddles and form an anticlinal ridge trending about north and south near its southern end and swinging around to the northwest at its northern end.

Outside of the Pennsylvanian series all sedimentary formations mentioned in this paper outcrop on the flanks and on the apex of the Salt Valley anticline. The general shape of the Salt Valley anticline is elliptical, the sedimentary beds rising toward the major axis of the structure at an average rate of 800 feet per mile. Erosion near the center of this structure has progressed to chocolate-colored shales and gypsum beds of Permian age. A scissors fault which pivots near the apex of this structure extends along the major axis from the northwest to the southeast ends of the anticline. The vertical displacement of the formations ranges from 1,000 feet

near the northwest end of the structure to 3,000 feet at the south end, where the Mancos shale rests against middle Permian formations. The average hade of the fault is 40 degrees northeast. Considerable block faulting has also taken place at the northwestern end of the structure and beds in the faulted block are so crushed, crumbled and broken that they could not be contoured. Near the central part of the structure there is a series of faults which finger out from the main fault and die out to the northwest. The vertical displacement along these faults increases to the southeast where they approach the La Sal Mountains. Structural conditions on the Moab anticline are very similar to those of the Salt Valley anticline and faulting is even more intense than on the Salt Valley anticline. The surface of the entire central part of this uplift is covered by recent sediments and wind-blown sand. Sedimentary formations from the top of the Wingate sandstone to the Pennsylvanian series outcrop in Moab Canyon. A strike fault extends along the west flank of the Moab anticline near its major axis for a distance of twenty-four miles. This fault can be followed over a distance of fourteen miles northwest of Courthouse, over which area it was mapped in detail by Lupton.¹ The downthrow side of this fault is to the northeast. Near Courthouse the vertical displacement amounts to 1,400 feet. In the "dugway" in Moab Canyon, nine miles southeast of Courthouse, Pennsylvanian limestones rest against the Upper Navajo sandstone and the vertical displacement of the sedimentary formations has increased to 3,500 feet. Block faulting appears to have taken place in Moab Valley proper. From the escarpments on both sides of Moab and Spanish valleys it is apparent that the displacement along the major fault increases to the southeast toward the La Sal Mountains so that general conditions of faulting on the Salt Valley and Moab anticlines are very similar in character.

Extensive faulting, which is so apparent on the Moab and Salt Valley anticlines, is almost entirely absent in the vicinity of Colorado River structures 1 to 4. Joints, traversing the formation in a northwest-southeast direction without displacement of formations,

¹ Charles T. Lupton, "Oil and gas Near Green River, Grand County, Utah," *U. S. Geol. Survey, Bull.* 541-D.

were noted on structures 1 and 2 while some minor block faulting was noticed at the southeast extremity of structure No. 2. Colorado River structures 1 to 4 are roughly elliptical in shape and their axes trend in a general north-south direction. These structures are outlined by high cliffs of Wingate sandstone, while Colorado River and its immediate tributaries have cut steep canyons into the Rico and upper part of the Hermosa formations at the center of the structures. Structures 1 to 4 exhibit 850, 550, 30 and 85 feet of closure respectively. The total area inside the closure of structures 1 and 2 amounts to 34 square miles, while the acreage of structures 3 and 4 within the closures is 4.7 and 5.5 square miles respectively.

OIL POSSIBILITIES

The horizons at which oil has been encountered in the southeastern part of Utah are the lower part of the McElmo formation and the Goodridge or Rico-Hermosa formations. The McElmo formation has been removed by erosion on all of the anticlines mentioned in this paper. The Rico and Hermosa formations are under cover on the Salt Valley anticline; the Rico and perhaps the upper part of the Hermosa are exposed along the Moab fault on the Moab anticline and they outcrop near the apices of Colorado River structures 1 and 2.

Oil in small quantities has been found near the top of the Goodridge in the San Juan field, San Juan County, Utah. The San Juan field is situated from fifty to seventy miles south of Colorado River structures 1 to 4. While lower sands are known to be present and oil seeps occur on at least one of them in the bottom of the canyon of San Juan River, no wells have as yet been drilled to test the lower unexposed part of the Hermosa formation in that field.

The entire Rico formation is exposed on structures 1 and 2 and the upper part of it is exposed on structures 3 and 4. The Rico or upper part of the Goodridge, which at present furnishes the oil of the San Juan field, can therefore not be looked upon as a possible horizon for oil and gas on the Colorado River structures. The uncertainty of exact correlation of the Pennsylvanian section has already been pointed out. At best, the entire lower part of the

Hermosa does not come to the surface anywhere in southeastern Utah so that the presence or absence of sands in it is problematical. With the exception of Cross and Ransome's section of the Rico quadrangle, Colorado, none of the sections which can be obtained in southeastern Utah, including the log of the well which was drilled into the Pennsylvanian at Moab, but which, according to latest reports, was drilling in the lower Hermosa beds at a depth of 2,823 feet, give any evidence as to the presence or absence of sands in the lower part of the Hermosa formation immediately overlying the Mississippian. The well at Moab is being drilled by the Big Six Oil Company on the west limb of the much faulted Moab anticline. The well penetrates Pennsylvanian formations in the main to the west of the fault. The upper 1,160 feet of this well pass through massive limestone beds with occasional very thin streaks of sand which have given oil and gas shows. These massive limestone beds probably represent the medial member of the Hermosa. The lower 1,100 feet penetrated by this well consist of black, brown, and gray shales, the former predominating. Three thin saturated sands were encountered in these shales at a depth of 2,200 feet. Gypsum, probably corresponding to the gypsum beds present in the lower Hermosa of southwestern Colorado, was encountered at 1,600 feet and 1,900 feet. This well is now drilling at 2,823 feet.

Due to the extensive angular unconformity affecting the Permian and Pennsylvanian formations, the limestone of the structure No. 1 section is absent or has changed laterally into sandstone or shale so that it cannot be identified at the section of formations at the Moab well. It is therefore somewhat difficult to predict what the drill will encounter on the Colorado River structures. While sands may be encountered for a depth of 950 feet below the apex of structure No. 1, there is a possibility that these sands are lenticular. For a depth of 950 to 2,000 feet thin sands may be present in the shale series while the beds below 2,000 feet have not as yet been penetrated by the drill. No very definite statement as to the presence or absence of sands in the lower Hermosa immediately overlying the Mississippian underneath the Colorado River structures can therefore be made until the Moab well has been completed or a test well has been drilled on one of these structures.

The well drilled on the Salt Valley anticline during the fall of 1918 and spring of 1919 is located within a faulted block near the northwestern end of this anticline. This well, which is 825 feet deep, probably penetrated broken formations of Mancos shale and Dakota conglomerate as well as the upper part of the McElmo formation and did not reach the Pennsylvanian formations. Salt and epsomite are reported from 775 to 825 feet.

The first well drilled on the Moab anticline, during 1919 and the spring of 1920, was abandoned at a depth of 2,450 feet. It was drilled by the Western Allies Oil Company and the Big Six Oil Company of Price and Moab, Utah. The well is located within a faulted block on the Moab anticline, the surface of which is covered with recent sediments which obscure structure and stratigraphy. Salt was encountered from 936 to 1,136 feet; this was underlain by 11 feet of oil sand, followed by 383 feet of salt. A 4-foot sand containing some oil was next encountered. The remaining beds passed through, from 1,534 to 2,450 feet, representing a thickness of 916 feet, consisted mainly of salt with occasional thin layers of sand and black shale. A qualitative analysis of this salt showed it to be mainly sulphate of magnesia with some sulphate of lime, a small amount of sodium chloride and a little iron. This well is located a short distance east of the main Moab fault.

CONCLUSIONS

The extensive faulting along the major axes of the Salt Valley and the Moab anticlines does no make them favorable for accumulations of oil in large quantities. As already indicated, the writer considers that the prospective oil and gas horizon on Colorado River structures 1 to 4 occurs in the lower part of the Hermosa formation. A well drilled on Colorado River structure No. 1 to a depth of not exceeding 3,000 feet would amply test the oil possibilities of this region.

The principal difference of opinion regarding the merit of the Colorado River structures probably arises over the possible presence or absence of oil sands in the lower Pennsylvanian and the top of the Mississippian series. The writer is aware of the fact that so far no oil is produced from this horizon along the western slope of the

Rocky Mountains with the possible exception of Soap Creek, Montana, and no oil seeps are known to the writer in the lower Pennsylvanian in southwestern Colorado. The nearest seeps are probably those in northwestern Wyoming.

However, as new oil and gas fields are discovered year by year, the areas on the North American continent, where oil and gas have not as yet been found and in which the exploration for these minerals may be considered a legitimate venture, are constantly becoming smaller. It appears that it will gradually become necessary for oil operators to adopt a more aggressive policy under which wells will be drilled in wildcat territory where there are unfavorable as well as favorable conditions for the accumulation of oil and gas in commercial quantities or where not all conditions bearing on such accumulation can be exactly determined beforehand. At best, the final test of any area regarding which there exists some difference of opinion among geologists is a well which penetrates *all* prospective horizons thought to be present within the reach of the drill. Formerly, no work was attempted in such areas or in others where conditions were generally favorable, but which were remote from producing fields or transportation facilities. However, as the now known oil and gas fields slowly become exhausted, such areas will no doubt receive their share of attention.

RESULTS AND PROSPECTS OF DEEPER DRILLING IN THE ROCKY MOUNTAIN FIELDS

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GENERAL STATEMENT

A comparatively rapid evolution in the development of drilling machinery covering the past 60 years has enabled the oil operator to delve deeper and deeper into the earth's strata in search for oil and gas. His efforts, in the majority of cases where oil or gas has been found rather near the surface and where drilling has been done on closed structures, have been rewarded by the finding of oil or gas in deeper reservoirs. This has been the history in practically all of the oil fields in the United States from the opening of the Pennsylvania fields, over 60 years ago, to the present.

The conditions in the Rocky Mountain region with respect to deeper drilling have not been unlike the history of deeper drilling in other oil fields of the United States, except that probably a smaller proportion of the structures have been tested to the deeper sands than in some of the other productive regions of the country.

It is the writer's object in this paper to present briefly the results which have been obtained by deep drilling in the Rocky Mountain region, and to point out certain possibilities of obtaining oil or gas in commercial amounts in structures which have not been drilled to the deeper sands. In doing this it will be necessary to give some of the history of development in the fields of the Rocky Mountain region and to refer to the stratigraphy of the various districts.

HISTORY

The earliest reference to oil in Wyoming, and possibly the entire Rocky Mountain region as far as the writer is aware, is contained in the notes of Captain Bonneville, made in 1833 and later worked into story form by Washington Irving. The locality described by Bonneville is part of the Dallas field a few miles south of Lander.

A little later another oil seep or spring was found in what is now known as the Plunkett field. Still later the Mormon emigrants found oil springs in southwest Wyoming. Then oil seeps were discovered near Alkali Butte and near Bonanza in Big Horn Basin. Particular attention is invited to the fact that no large amounts of oil or gas have been found near these oil springs or seeps either in shallow or deep sands, although all of the areas mentioned seem to have been tested through all possible reservoirs. With regard to oil springs or seeps in the Rocky Mountain fields, the situation can be briefly summarized by the statement that none of the principal producing fields—Rock River, Lost Soldier, Grass Creek, Elk Basin, Big Muddy in Wyoming, or Cat Creek and Soap Creek in Montana—have known oil springs or seeps on them. The one exception is the Salt Creek field which has several seeps not far from the crest of the structure.

Development work in the oil fields of the Rocky Mountain region has revealed the fact that practically all oil found above the base of the Cretaceous rocks is light, high-grade, paraffin base oil ranging in gravity from about 34 degrees Baumé, in case of oil from the Big Muddy field, to 60 degrees Baumé, as reported from the Hogback structure recently discovered by the Midwest Refining Company in northwestern New Mexico. Practically all oil found in pre-Cretaceous rocks in the Rocky Mountain region is heavy, low-grade asphalt base oil ranging from about 20 degrees Baumé to a little more than 30 degrees. One notable exception to the statement just made is the oil found in the San Juan field, Utah, where oil of paraffin base and having a gravity of more than 40 degrees Baumé occurs in rocks of Pennsylvanian age.

It is interesting to note the change in opinion of geologists and oil operators as oil and gas have been discovered in new districts and in new horizons in old districts.

Many of us recall that Grass Creek was not looked upon favorably by some prior to discovery of oil there because it was too large; the objection to Elk Basin was that it was too much faulted; the handicap of Big Muddy field was the lack of sufficient closure; and Cat Creek was not likely to produce oil for the reason that the Frontier or Wall Creek sands were lacking and that no oil in com-

mercial amounts had yet been found in Montana. After drilling, all of the fields mentioned yielded oil in large amounts and are still producing. The above illustrations are given to show that we oil geologists have a tendency to be somewhat pessimistic rather than the opposite when considering possible new districts and possible new horizons at greater depths.

Our ideas of what constitutes really a deep test have undergone considerable change during the past few years. Many of us remember in 1916, about the time the Big Muddy field was opened, that the first well there to the First Wall Creek sand at a depth of 3,000 to 3,100 feet was considered a very deep test for the Rocky Mountain region. Since that time many wells have been drilled to 4,000 feet or more and one well in western Nebraska was drilled to around 5,500 feet without great difficulty. Of course there is a limit to which oil operators can drill at present, but with improved methods in drilling the present limit will probably be increased. The deepest well in the United States was drilled to more than 7,000 feet in depth. It seems reasonable to predict that within a few years we shall see many wells drilled to 6,000 feet or more if stratigraphic conditions warrant and the demand for crude petroleum increases as it is very likely to do.

Our ideas relative to sands likely to carry oil and gas in commercial amounts have also undergone considerable change since 1916. At that time it was thought that if the Frontier sands did not carry oil or gas in commercial amounts, there was little use in going deeper, for the reason that the Embar sand, the only other known productive horizon, is some 2,000 feet deeper and was not worth drilling to, as its oil is low-grade, low-priced, and the production small judging from results in the Lander fields, the only heavy oil-producing area then in the Rocky Mountain region. It is true that the Torchlight and Greybull fields were producing a little oil from the Mowry shale and the Greybull sand respectively, but it was thought that these were freakish and that these horizons held little promise of carrying much oil in untested areas. One of the reasons for placing little hope in the Dakota or Greybull sand was the fact that it is a blanket sand carrying water in large quantities and under heavy pressure and therefore any oil it might once have contained would have been flushed out of the structures

and carried away. Another reason for holding out little hope at that time for the Dakota sand as an oil reservoir was the scarcity of carbonaceous material in beds underlying this sand. The possibility of oil migrating downward or laterally from stratigraphically overlying beds of Benton age was hardly given thought. Since that time much oil and gas have been produced from the lower part of the Cretaceous in both Wyoming and Montana.

The Sundance formation, marine Jurassic, was considered of little importance a few years ago as a possible source of oil, for the reason mainly that no oil or gas had been found in commercial amounts in this formation and that the formation is practically devoid of organic shales. Our ideas have been entirely modified during the last two or three years due to the discovery of oil in commercial amounts in the Sundance formation in the Bolton Creek field in Wyoming and in the Ellis formation of the same age on the Sweet Grass arch in northern Montana.

The oil spring discovered by Captain Bonneville in the Dallas field near Lander issues from the Chugwater formation. Although this spring occurs in the red beds and most of the oil recovered from the Dallas field has been found in a sand in this formation, practically every oil geologist believed that the oil had originated, not in the red beds, but in the underlying Embar or lower beds and that the oil had migrated upward through fault-planes and joints. Deeper drilling in the Lander fields and also in the Hamilton dome field in Big Horn basin has proved conclusively that the source of the oil in the red beds is from the underlying Embar and possibly lower formations.

The existence of oil in the Tensleep sandstone was proved first in the Hudson field near Lander and later in the Crystal Creek structure, north of Greybull, in Big Horn basin. The Tensleep also carries oil in the Soap Creek field in southern Montana.

A little oil was found in the Amsden formation in the Crystal Creek structure but more is present in this formation in the Soap Creek field.

The only area where the top of the Madison limestone, of Mississippian age, is known to carry oil in commercial amounts is in the Soap Creek field in southern Montana. In this particular locality the top of the Madison seems to be considerably fractured,

explaining thus the reservoir space which is present. Where this condition exists in other localities in the Rocky Mountain region we may reasonably expect to find some oil in the upper part of the Madison limestone. In places in the Rocky Mountain region the Madison limestone gives off a strong odor of crude oil from freshly broken surfaces. One easily accessible place where this phenomenon may be observed is in Sheep Mountain canyon about 20 miles north of Greybull in Big Horn basin, Wyoming.

Oil in commercial amounts may be found in beds lower than the Madison limestone in the Rocky Mountain region but this seems doubtful, for in most of Wyoming and Montana the underlying rocks are of Cambrian age and contain little carbonaceous material. In parts of central Wyoming the Madison is underlain by limestone of Ordovician age, but the presence of these beds does not improve the situation as concerns the finding of oil below the Mississippian.

PRODUCTIVE ZONES

The following paragraphs present a summary of the numerous sands which carry oil or gas in small or large amounts in the Rocky Mountain region. These are arranged in order from the youngest to the oldest.

Tertiary.—For several years oil has been obtained from a tunnel in the Green River formation near Dragon in eastern Utah. Gas was found a number of years ago in the Wasatch formation on the White River dome in western Colorado. This gas is still flowing and is reported to be somewhat "wet." A deep well will probably be drilled on this structure in 1923. The total thickness of the Wasatch in this particular district is approximately 3,500 feet. No zones productive of oil or gas are known in the Fort Union or Lance.

Upper Cretaceous.—To date the upper part of the Upper Cretaceous system down to the Mesaverde formation has not yielded oil or gas in commercial amounts. Gas has been found in sandy members of the Mesaverde southeast of the Grass Creek field in what is known as the Golden Eagle structure.

In the underlying Pierre shale the Shannon sandstone lenticles and other sandy zones have been found to contain oil in the following

fields: Boulder and Rangely, in Colorado; and Big Muddy, Big Piney, La Barge, Pilot Butte, Teapot, Shannon and possibly the Ferris field, in Wyoming. The oil in the Florence field, Colorado, occurs in joints and fractures in the Pierre shale and not in sandy beds.

No oil or gas is known in the Niobrara in the Rocky Mountain region except possibly at Wray, Colorado, where gas is present.

The most productive formation of the Rocky Mountain region is the Benton which contains the rich Frontier and other sands. Near Thornton, Wyoming, small amounts of oil have been found on a monocline in lenses of sand in the Carlile shale. The Frontier sands have been variously designated as Wall Creek sands, Grass Creek sands, Elk Basin sands, and Torchlight and Peay sands, and the following fields produce oil or gas from them: Salt Creek, Grass Creek, Elk Basin, Big Muddy, Lost Soldier, Byron, Torchlight, Alkali Butte, Hidden Dome, Rock Springs, Little Buffalo Basin, Big Sand Draw, and Powder River Station, all in Wyoming; and probably the Southern Ute structure in New Mexico. The Mowry shale beneath the Frontier carries oil in small or large amounts in its sandy phases in Torchlight, Ferris, Lost Soldier, Rock River, Plunkett, and Wertz structures, all in Wyoming. The Thermopolis shale contains in its lower half a somewhat lenticular sandstone known locally as the Muddy or Newcastle sand, which carries oil or gas in the following Wyoming fields: Rock River, Lost Soldier, Lance Creek, Allen Lake, Mahoney, Osage, Spring Valley, Ferris, and Wertz.

The Dakota sandstone or its equivalent yields oil or gas in the following fields: Greybull, Big Muddy, Elk Basin, Lance Creek, Poison Spider, Rock River, Salt Creek, and possibly Lost Soldier, all in Wyoming; Southern Ute, New Mexico; Williams Park, Colorado; and Cat Creek, Montana.

Lower Cretaceous.—This system includes the Fuson, Kootenai, and Cloverly, except the upper sand and possibly the Morrison. The Fuson shale, underlying the Dakota, is barren of oil and gas as far as is now known. The Kootenai and Cloverly, excluding the upper sand of each which probably corresponds to the Dakota, yield oil in the following fields: Greybull, Cat Creek, Big Muddy,

Byron, Ferris, Mahoney, Mule Creek, Wertz, Sweetgrass arch, Salt Creek. The Morrison formation carries oil in Grass Creek and gas in Byron.

Jurassic.—The Sundance formation and its Montana equivalent, the Ellis, yields oil or gas in the Bolton Creek and Poison Spider fields in Wyoming, and on the Sweetgrass arch in Montana. Oils found in the Jurassic and lower rocks in the Rocky Mountain region are prevailing of asphalt base and are of a lower grade than the oils obtained from younger formations.

Triassic.—Oil has been found in the Chugwater formation red beds in the Dallas and Hamilton Dome fields in Wyoming. This oil is heavy and probably migrated from the underlying Embar and lower beds.

Permian.—The Embar formation, in part if not all of Permian age, carries oil in the Maverick Springs, Hudson, Dallas, Hamilton Dome, Grass Creek, Warm Springs, and Cow Gulch areas.

Pennsylvanian.—The Tensleep sandstone and Amsden formation underlie the Embar, and overlie the Madison limestone. The Tensleep yields oil at Soap Creek, Montana; Crystal Creek and Hudson, Wyoming. The Goodridge sand which carries the light oil referred to above in the San Juan field, Utah, is approximately equivalent to the Tensleep. The Amsden formation which underlies the Tensleep, carries oil in the Soap Creek field in Montana.

Mississippian.—The fractured beds at the top of the Madison limestone in the Soap Creek field, Montana, yield oil in commercial amounts.

Summary.—From the preceding résumé of the productive zones in the geologic section of the Rocky Mountain region, it will be noted that oil or gas has been found in nearly all of the formations from middle Tertiary to Mississippian. The only formations barren of oil or gas to date are the Fort Union, Lance, Laramie, Lewis, and Fuson. It therefore seems reasonable to believe that much oil and gas will be produced by deep drilling, especially where the structures are well closed and the surface rocks belong to that part of the Cretaceous below the base of the Mesaverde. In other words, if the top of the Madison limestone is within 5,500

to 6,000 feet of the surface it is worth drilling if the structure is well closed.

REVIEW OF DRILLING IN ROCKY MOUNTAIN FIELDS

We may next consider what has been done in the more important fields of the Rocky Mountain region in drilling to the deeper sands. In considering these fields we shall as nearly as possible refer to them in order of their importance.

Salt Creek.—The deepest well stratigraphically in the Salt Creek field penetrated the Lakota sandstone at approximately 2,600 feet in depth near the crest. Considering the thickness of the underlying formations, the upper part of the Madison limestone can be penetrated by a hole somewhat less than 5,000 feet deep. A structure such as Salt Creek is well worthy of a test to the depth mentioned, especially with seven possibly productive zones below the horizon of the bottom of the deep test mentioned.

Rock River.—The deepest well stratigraphically in the Rock River field penetrated the Morrison formation at around 3,300 feet. In order to penetrate the equivalent of the top of the Madison in this area, it would require a hole approximately 5,800 feet deep. No heavy oil has yet been found in the pre-Cretaceous in southern Wyoming, yet this fact does not preclude the possibility of future discovery.

Lost Soldier.—The deepest well stratigraphically in the heart of the Lost Soldier field is approximately 2,000 feet deep. The top of the Madison limestone can be penetrated at this locality by a well around 4,500 feet deep. A test to the deeper horizons in the Lost Soldier field, where so much high-grade oil is being produced, is advisable.

Cat Creek.—The deepest well stratigraphically in the Cat Creek productive area has penetrated the second sand of the Kootenai at a depth of about 1,300 feet. To penetrate the top of the Madison limestone where some of the production in the Soap Creek field is obtained, would require a hole somewhat less than 3,800 feet. Such a test is advisable as beds in the lower Kootenai, Morrison, Ellis, Quadrant, and upper part of the Madison may be productive.

Grass Creek.—The Tensleep sand has been penetrated in the deepest well stratigraphically, approximately 4,200 feet deep, in the Grass Creek field. To reach the upper part of the Madison limestone would require a hole not to exceed 4,500 feet. Such a test is certainly worth while, as two possibly oil-bearing horizons are untested in this structure at present.

Big Muddy.—The deepest test in the Big Muddy field penetrated a short distance below the Lakota sand and reached a depth of approximately 4,400 feet. Oil is reported from both Dakota and Lakota. It will be possible to test the Morrison and Sundance formations, but not the Embar, Tensleep, and Amsden with present drilling machinery in a 6,000-foot hole.

Elk Basin.—In the Elk Basin field the deepest well stratigraphically, in the heart of the structure, has penetrated the Muddy sand of the Thermopolis shale and possibly the top of the Dakota sandstone, at a depth of a little less than 2,400 feet. A strong flow of gas was encountered near the bottom of the hole. In this field, a test to the top of the Madison limestone is worth while, and this depth can be reached by a hole around 4,500 feet deep. The strong gas pressure, however, will constitute a hindrance in reaching this depth.

Maverick Springs.—In the Maverick Springs field the surface rocks belong to the upper part of the Chugwater formation, hence the drilling depth to the Embar sand in the heart of the field is approximately 1,500 feet. In order to penetrate the top of the Madison limestone, it would not require a hole deeper than 2,300 or 2,400 feet. Deeper drilling in this field is certainly worth while, as three possible oil-bearing horizons are within easy reach of the drill below the Embar.

Soap Creek.—The Soap Creek field has been tested down to and including the top of the Madison limestone. It seems, therefore, that Soap Creek has been thoroughly tested, though deeper drilling into the Madison may reveal other pay sands.

Sweet Grass Arch.—The deepest well stratigraphically on the Sweet Grass arch reached a depth of a little more than 2,600 feet, and probably penetrated the top of the Devonian. Deeper drilling may reveal deeper productive horizons, but this seems doubtful.

Osage.—The Osage field just west of the Black Hills in Wyoming is not a well-closed structure. The presence of oil in this field is due largely to the fact that the Muddy sand which carries the oil is lenticular. Wells drilled to the Dakota and Lakota sands get large flows of water. It seems doubtful if deeper drilling in the Osage field will reveal deeper oil-saturated sands.

Mule Creek.—Oil in the Mule Creek field occurs mainly in the Lakota sand of the Lower Cretaceous. The Minnelusa, the approximate equivalent of the Embar sand, can be reached by drilling a hole about 2,600 feet deep. Such drilling will probably not be tried here until crude oil is in greater demand and the price higher.

Lance Creek.—Oil in the Lance Creek field is found mainly in the Muddy and Dakota sands at depths of 3,500 to 3,700 feet. Considering the results of drilling in this field to date, it seems doubtful if attempts will be made to reach the other eight possibly oil-bearing zones under this structure, until crude petroleum is in much greater demand. The Minnelusa and even the top of the equivalent of the Madison lime can be reached in the heart of the field by a hole less than 6,000 feet deep.

Byron.—The strata in the heart of the Byron field have been penetrated to the Morrison formation at depths of 2,600 feet or less. It seems reasonable to expect that some of the six untested possibly oil-bearing horizons will carry oil or gas in commercial amounts.

Greybull and Torchlight.—Both of these structures have had deep tests drilled on them without encouraging results. Neither deep test, however, reached the top of the Madison limestone. The comparatively small closures of both of these structures does not make either of them particularly attractive areas in which to drill deeper than already tested.

Pilot Butte.—The Pilot Butte field is reported to have been drilled to approximately 3,200 feet with the only commercial oil being found in sandy shale at a depth of about 500 to 600 feet. A structure such as this should be given a thorough test to at least 4,500 feet.

Rock Springs.—The Rock Springs structure has been tested to a depth of approximately 3,000 feet. The only results to date are wells of gas. A structure with the closure and size of this one

should be thoroughly tested to a depth of 5,000 feet at least, unless prevented by strong gas pressure.

Untested structures of Tertiary surface.—There are numerous localities in the Rocky Mountain region where slight structures are present in the Tertiary. These slight deformations in the Tertiary probably mean more pronounced structures in the underlying Cretaceous and older beds. Such structures will have to be drilled, and some of them quite deep, before all the possibilities of obtaining oil in the Rocky Mountain region are exhausted.

SUMMARY

In the various fields of the Rocky Mountain region where deep drilling has been done additional production of oil or gas has in most cases been found. This fact alone, it seems to the writer, is sufficient to warrant the oil operator in drilling deeper on those favorable structures where possible oil-bearing zones are yet untested. Of course, the present price of crude petroleum does not encourage deeper drilling, but as the demand for petroleum and its products increases, the price of crude will advance, and deeper drilling will result naturally from economic causes.

DISCUSSION

E. B. HOPKINS: I think that the discovery of oil in the Madison is very important for Wyoming, because the discovery of new structures is very difficult, since the ground has now been very thoroughly explored. On the other hand many structures have been overlooked because the known sands are either exposed or too near the surface.

E. M. PRICE: Attention may be called to the fact that a well on the Gas Ridge dome, in the Sweetgrass arch, has been drilled through the Madison lime of Mississippian age, into the Devonian shale. No production was found in the Devonian. This is confirmed by D. E. Hageman and C. J. Hares.

MAX BAUER: Commercial gas has been produced for some time from the lower part of the Bearpaw shale on the Glendive anticline near Baker, Montana. At least the gas is coming from a sandy bed at a depth of 700 to 800 feet. This sandy shale may correlate with the Judith River; nevertheless it is near the base of the Bearpaw.

Another point which I wish to bring out is that oil below the Dakota group or Cloverly is not always black or heavy oil. The oil from the Ellis formation of Jurassic age on the Sweetgrass arch carries 20 per cent gasoline and is about 34° Baumé gravity.

GEOLOGIC FORMATIONS OF A PART OF SOUTHERN CALIFORNIA AND THEIR CORRELATION¹

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The last decade has shown a remarkable growth in the oil industry of southern California, but the study of the geology of the region with which the occurrence of petroleum is so closely associated has not kept pace with the development. Comparatively little was done to unravel the stratigraphic history of this region from 1907, when Eldridge and Arnold's² work appeared, until 1917, when a systematic investigation of the geology of the region south of San Joaquin Valley was undertaken by the United States Geological Survey. At the present time detailed mapping has been completed over the greater part of the area between latitudes $34^{\circ} 30'$ and $33^{\circ} 35'$, which includes the Santa Clara River drainage basin east of Santa Paula, Fernando Valley, a large part of Santa Monica Mountains, the Los Angeles Basin, San Pedro Hills, Puente Hills, San Jose Hills, and a part of Santa Ana Mountains and San Joaquin Hills. The writer has been responsible for all this work except that in Puente Hills, San Jose Hills, and Santa Ana Mountains, which was completed by W. A. English.

In the course of this survey it became apparent that the stratigraphic column as set forth by Eldridge and Arnold could be worked out to advantage in more detail. Therefore, a revised column has been prepared according to the results of this geologic study, showing the sequence of the formations in a part of southern California and correlating them with the formations as given in previous reports of the same region by the United States Geological Survey. The noticeable changes in the column are the threefold division of the Eocene (the Meganos formation having been added),

¹ Published by permission of the Director of the U. S. Geological Survey.

² George H. Eldridge, and Ralph Arnold, "The Santa Clara Valley, Puente Hills, and Los Angeles Oil Districts, Southern California," *U. S. Geol. Survey Bull.* 309, 1907.

the introduction of the new formational names Topanga and Mint Canyon, and the restriction of the term Vaqueros.

No attempt has been made in the accompanying classification to represent graphically the thickness of each formation. These vary greatly from place to place, so that what applies in one locality is not applicable in another. Also, the study of the region in southern California shows that every geologic province has had its particular history, and that whereas a well-defined hiatus may exist at one locality, it is represented by continuous deposition at another. Even in the short distance between Santa Monica Mountains and Santa Clara Valley there are marked differences in the geologic history of the two regions or provinces.

A general description of the stratigraphic relations of the formations, together with their geologic age and principal exposures, follows. The discussion of their lithology is not given, as that involves too much detail for a paper of this kind, and a general statement is really insufficient for the reason that the lithologic characteristics of the formations change from place to place. It must be borne in mind that a detailed study of the geology of southern California is far from complete. Other formations than those given here may be added and the status of those described may be materially revised by future work.

PRE-JURASSIC

Metamorphic rocks.—These rocks are fairly common wherever the older crystallines which comprise the basement complex are exposed. They consist principally of schists, with minor amounts of quartzite and limestone, the age of which is not definitely known except near Cajon Pass, where fossils of Paleozoic age are found in some limestone, and in Santa Ana Mountains, where fossils of Triassic age occur. It is probable that some of the gneissic granites in this region are of pre-Jurassic age.

PRE-CRETACEOUS (?)

Granites (Jurassic?).—Granites have intruded the rocks of pre-Jurassic age, the result of which is thought to be the primary cause of the metamorphism in the older sedimentaries. These granites range in composition from true granites to norites, but the

GEOLOGIC AGE	ELDRIDGE AND ARNOLD 1907 U. S. G. S. Bulletin 309			KEW 1919 U. S. G. S. Bull. 691		KEW 1923 This paper		STANDARD SECTION OF THE CALIFORNIA COAST RANGES B. L. CLARK <i>(Jour. Geol., Vol. 29, 1921, chart opposite p. 586)</i>	
	Santa Clara District	Puente Hills	Los Angeles District	Simi Valley	Part of Southern California				
QUATERNARY	Alluvium	Pleistocene	Quaternary 1-600'	Alluvium	Alluvium				
	Pleistocene deposits			Terrace gravels	San Pedro formation	Upper beds Terrace deposits Lower beds			
PLIOCENE	Miocene, Pliocene, Pleistocene Fernando formation 5000'-6000'	Fernando formation 1500'-2000'	Fernando formation 2000' ± Sandstone and shale 1000' Shale 500' Sandstone and sandy shale 500'	Absent Fernando formation 1000' ± [Absent]	Fernando Group	Saugus formation (Upper Pliocene and Pleistocene) 2000' Probably equivalent in part to San Diego formation Pico formation (Lower Pliocene) 4000' ±	Saugus	Merced	
MIOCENE	MIOCENE Modelo formation 1700'-6000' Vaqueros formation 2000'-3000' [Absent(?)] <i>[May be represented in basal part of Modelo]</i>	Intrusive diabase Upper shale 300'-400' Sandstone 300'-1000' Puente formation 2600'-3400' Lower shale 2000'	Intrusive Diabase and Basalt Upper Puente shale 2000' Sandstone 2000'	Upper shale of Eldridge absent Intrusive basic rocks Sandstone No. 1 3000' ± Shale 1700' ± Sandstone No. 2 2500' ± Modelo formation 8700' ± <i>(redefined)</i> Vaqueros sandstone 100'-1700' ± [Absent in places]		Intrusive basic rocks Modelo formation (upper Miocene) 9000' ± Mint Canyon formation (upper Miocene) 4000' ± Topanga formation (middle Miocene) 6000' ± Vaqueros formation (lower Miocene) 100'-1800' ± Sespe formation 4000' ± Absent Tejon formation Martinez formation Chico formation [Absent] [Absent] [Absent]	Santa Margarita San Pablo Series Briones Monterey Series Undifferentiated "Monterey Shale" Temblor Vaqueros		
OLIGO- CENE (?)	Eocene, Oligocene, or Miocene Sespe formation 3500'+ White sandstone green and pink shale 400'-500'	[Absent]	[Absent]					San Lorenzo Series	
Eocene	Eocene Topatopa formation 5500'+ Shales and sandstones 3500' Quartzites and sandstones 2000'					Tejon formation (upper Eocene) 2000' ± Meganos formation (middle Eocene) 2000'-3000' ± Martinez formation (lower Eocene) 1500'-3500' ± Chico formation (Upper Cretaceous) 5500' ± Trabuco formation (<i>correlation uncertain</i>) Absent Franciscan (?) formation Granitic rocks Metamorphic rocks	Tejon	Meganos Martinez	
CRETACEOUS	[Absent]	[Absent]	[Absent]						
JURASSIC (?)	[Absent]	[Absent]	[Absent]						
JURASSIC (?)			Granite						
PRE-JURASSIC	Granitic basement		Black schist						

prevailing type is the granodiorite. Their age probably corresponds, in general, to the granite of the Sierra Nevada, which is considered to be late Jurassic or early Cretaceous.

Franciscan (?) formation (Jurassic?).—Rocks resembling in lithology those comprising the Franciscan formation of middle California are found on the Channel Islands off the coast of southern California and at one locality on San Pedro Hill, Los Angeles County. The strata exposed at the latter place consist principally of banded quartzite, crossite and glaucophane schist, and metamorphosed sandstone. On Catalina Island serpentine is also associated with these rocks. No evidence bearing on the age of the formation is present in this region.

CRETACEOUS

Trabuco formation.—This formation, the oldest part of the Cretaceous which has so far been recognized in southern California south of latitude $34^{\circ} 30'$, was described by Packard¹ from the west side of Santa Ana Mountains. It was considered by him to represent a phase of the Cretaceous slightly older than the Chico formation (Upper Cretaceous) which lies above it unconformably. Whether it belongs to the Chico or is to be correlated with the Horse-town or Knoxville is uncertain.

Chico formation (Upper Cretaceous).—Rocks comprising this formation are widespread in California, cropping out at numerous localities southward into Lower California. In the vicinity of Los Angeles Cretaceous rocks have been definitely correlated with the Chico formation on the basis of fossils.² In southern California areas of this formation occur in Simi Hills, Santa Monica Mountains, Santa Ana Mountains, and along the coast in San Diego County. Wherever exposed it rests unconformably below the Eocene. No oil is known to occur in the Cretaceous rocks of southern California.

EOCENE

Martinez formation (lower Eocene).—Although the Martinez formation was first described from the San Francisco Bay region,

¹ E. L. Packard, "Cretaceous of Santa Monica Mountains, Southern California," *Calif. Univ. Publ. Bull. Dept. Geol.*, Vol. IX (1916), No. 12, pp. 137-59.

² E. L. Packard, *op. cit.*

the best section in California is found on the north side of Simi Hills, Ventura County. Here it rests unconformably upon the Chico formation (Upper Cretaceous) and below the Meganos formation (middle Eocene). Other localities at which the Martinez formation occurs are Santa Ana Mountains and at Rock Creek, on the northeast slope of San Gabriel Mountains. In every place the determination of the age of the Martinez formation was made on the basis of paleontology.

Meganos formation (middle Eocene).—In 1918 Dr. Bruce L. Clark,¹ of the University of California, recognized the threefold division of the Eocene on the Pacific Coast, calling the additional third division the Meganos. This part of the Eocene was hitherto included with the Tejon formation (upper Eocene). The validity of this formation is now well established and the unconformable relations between it and the Martinez formation below and the Tejon formation above have been shown to exist in many places. One of the best exposures of the Meganos formation is in Simi Valley, where its stratigraphic position is distinct and its age is definitely determined by its fauna.

This formation is considered to be the source of the oil in Simi Valley and in the Oak Ridge-South Mountain fields, Ventura County.

Tejon formation (upper Eocene).—After the recognition of the Meganos formation and its separation from the Tejon formation, very little was left, it seemed, to represent the upper Eocene on the Pacific Coast. Fortunately the type section of the Tejon, located at old Fort Tejon, in Tejon Pass, at the south end of San Joaquin Valley, has remained intact and is characterized by a marine fauna fairly distinct from the marine fauna of the Meganos formation. Although the Tejon at the type locality rests directly upon the granite, farther west the same section overlies the Meganos with a marked unconformity.²

In southern California the Tejon formation is found in Ventura County in Santa Ynez Mountains and Topatopa Mountains,

¹ B. L. Clark, "Meganos Group, a Newly Recognized Division in the Eocene of California," *Bull. Geol. Soc. America*, Vol. XXIX (1918), pp. 281-96.

² B. L. Clark, "The Stratigraphic and Faunal Relationships of the Meganos Group, Middle Eocene, of California," *Jour. Geol.*, Vol. XXIX (1921), No. 2, pp. 145-54.

where it is included in the Topatopa formation, and in Simi Valley. It is present also in Santa Ana Mountains and in San Diego County.

It acts as a reservoir for part of the oil occurring in the Tapo Canyon field of Simi Valley, and is also known to be petroliferous, though not commercially important, in other parts of Ventura and Santa Barbara counties.

OLIGOCENE(?)

Sespe formation.—The Sespe formation is composed of strata resembling deposits commonly formed in a large valley under arid or semi-arid conditions. It has been definitely recognized only in the region northwest of Los Angeles, with its type locality situated on Sespe Creek near the town of Fillmore, Ventura County. It also occurs at many other places from Santa Ynez Mountains to Santa Monica Mountains. As a rule it rests unconformably upon the Eocene, but is conformable above with the Vaqueros formation (lower Miocene). In the absence of paleontologic data this formation is doubtfully referred to the Oligocene series.

The oil measures of the Oak Ridge-South Mountain fields occur in the lower part of the Sespe formation. Oil is also present at the same horizons in Simi Valley.

Strata questionably of Sespe age occur in the upper part of the Santa Clara River drainage area and have been called the "Escondido series" by Hershey, but that name is pre-empted by an Upper Cretaceous formation of Texas. Lack of fossils and clear stratigraphic relations have prevented a definite correlation for these beds. Strata having a lithology similar to the Sespe are also present in Santa Ana Mountains, but as these beds contain lower Miocene (Vaqueros) fossils it is the writer's opinion that they should be correlated with the Vaqueros formation.

Although marine Oligocene formations are present in central California and in Oregon and Washington, no such formations have been recognized south of San Joaquin Valley.

MIOCENE

Vaqueros formation (lower Miocene).—In some of the literature discussing Miocene stratigraphy of California the Vaqueros has been used to include strata containing faunas of lower, middle, and,

in some places, upper Miocene age. Recent work has shown that it is advisable to confine the name Vaqueros to rocks containing the fauna which occurs in the Vaqueros formation at its type section on Vaquero Creek, Monterey County, and not to include the younger series of strata which contains a fauna comparable to the "Temblor" fauna of San Joaquin Valley. The true Vaqueros is characterized by certain fossils, the more common ones being *Turritella ineziana* and *Pecten magnolia*, which assemblage of species is commonly called the *Turritella ineziana* fauna. Strata representing this geologic horizon occur closely associated with the non-marine Sespe formation (Oligocene?) in southern California at Sespe Creek, Oak Ridge, and Simi Valley in Ventura County, where no unconformity has been recognized between them. In the Los Angeles City district, Santa Ana Mountains, San Joaquin Hills, and possibly in Santa Monica Mountains, the Vaqueros rests upon strata of pre-Miocene age. Its relation to the younger Topanga formation is given in the discussion of that formation which follows.

No oil-bearing strata occur in the Vaqueros of southern California except in the Sespe Creek district of Ventura County.

Topanga formation (middle Miocene).—Until recent work by the writer in Santa Monica Mountains the series of strata here designated as the Topanga formation has been included within the Vaqueros formation, the latter name being used for all Miocene rocks below the so-called "Monterey shale" or Modelo formation and included within the Monterey group. The formational name Topanga, which is here proposed by the writer, is defined to include those rocks lying below the Modelo formation (upper Miocene) and above the Vaqueros formation (lower Miocene) and containing a fauna commonly referred to as the *Turritella ocoyana* fauna, which is probably equivalent in age to the "Temblor" fauna of San Joaquin Valley. The strata are essentially sandstone, in contrast to the Modelo formation above, which contains terrigenous shale with some cherty and, in places, diatomaceous beds. At Topanga Canyon, Los Angeles County, from which the name is taken, the beds lie with a marked unconformity below the Modelo shales and sandstones. This unconformity has not been recognized in every locality where these formations are present, so that the Topanga

appears in places to grade up into the Modelo formation. Where the Topanga overlies the Vaqueros, which contains the *Turritella ineziana* fauna, as in Simi Valley, Santa Ana Mountains, and San Joaquin Hills, an unconformity between the two has been reliably reported. This formation has been recognized over a large area, but is best developed in Simi Hills, Santa Monica Mountains, Puente Hills, Santa Ana Mountains, and San Joaquin Hills. The Topanga is equivalent to the lower part of the Monterey group of middle California. It is not known to be oil-bearing in southern California.

Mint Canyon formation (upper Miocene).—The formation to which the new name Mint Canyon is here applied is locally developed in the vicinity of Mint Canyon, a branch of the upper part of Santa Clara River north of San Gabriel Mountains. It is a land-laid deposit, similar in lithology to the Sespe formation (Oligocene?). Its age has been determined by a good vertebrate fauna, found at various horizons, which has been identified by Dr. Chester Stock, of the University of California, as being of upper Miocene age and equivalent to the Barstow fauna, from Mohave Desert, described by Dr. John C. Merriam. Its relation to the marine horizons is clear, in that it rests unconformably upon beds which are probably equivalent to the Sespe formation and below strata containing a fauna of upper Miocene age which have tentatively been correlated with the Modelo formation. Where the latter formation is absent the Mint Canyon rests unconformably below the Pico formation (lower Pliocene). The Mint Canyon formation is interesting in that it is a connecting link between the formations of the Great Basin and those of the Pacific Coast province.

Modelo formation (upper Miocene).—The Modelo formation was first described by Eldridge and Arnold¹ from Modelo Canyon, on the north side of Santa Clara Valley, Ventura County. In recent studies of the writer he has correlated the Modelo at the type section with lithologically similar beds occurring in Santa Monica Mountains, the Los Angeles City district, and Puente Hills. In these areas, south of Santa Clara Valley, the strata were called the

¹ *Op. cit.*, pp. 17-22.

Puente formation by Eldridge and Arnold, but were considered to be equivalent to the Modelo.¹

Due to the similarity in lithology between the Modelo formation and the Monterey deposits of the type section at Monterey, California, and for the reason that it has been customary to apply the name Monterey to any series of strata which contains diatomaceous or silicious shales, the Modelo has heretofore been correlated with that group. Whether they are equivalent in age the writer cannot state, as the localities where definitely known strata of Modelo and Monterey age occur have not been connected by mapping, and fossils have been found in basal beds of the Modelo in Santa Monica Mountains which indicate that the formation is of upper Miocene age and apparently younger than the rocks of the Monterey group of middle California. The commonest species, *Pecten raymondi* Clark, is a form which is found in strata not older than the Santa Margarita formation (upper Miocene) of middle California. A sea urchin is also present, which is probably an *Astrodapsis*, a genus not known to exist below the upper Miocene. As the Santa Margarita formation has never been recognized in southern California it is possible that the Modelo may represent it.

The Modelo formation is important in that its organic shales are the source of and its sands a reservoir for a large part of the petroleum in southern California.

PLIOCENE AND LOWER PLEISTOCENE

Fernando group.—The well-known term Fernando (first used by Eldridge and Arnold)² is a group name for the strata, herein defined as Pico and Saugus formations, which overlie the silicious shales and massive sandstones of the Modelo formation. Within the last few years it has been shown that this group of strata is divisible into two unconformable formations. The lower formation contains a fauna of lower Pliocene age and the upper formation (the Saugus formation of Hershey) contains a fauna of upper Pliocene and lower Pleistocene age. The lower formation (described by English³ as lower Fernando), which is well exposed in Elsmere

¹ *Idem.*, p. 143.

² *Op. cit.*, p. 22, 1907.

³ W. A. English, "The Fernando Group Near Newhall, California," *Calif. Univ. Dept. Geol. Bull.*, Vol. VIII (1914), pp. 203-18.

Canyon, near Newhall, Los Angeles County, and also in Pico Canyon, Los Angeles County, has recently been named by the author¹ Pico formation, from its exposures in the canyon of that name. For the upper formation Hershey's name Saugus is retained.

Pico formation (lower Pliocene).—The author's name Pico formation, for the lower formation of the Fernando group, first appeared in print in 1921, in a brief paper by B. L. Clark on the Los Angeles region. The formation is well exposed in Pico Canyon, Los Angeles County, from which it is named. It is also well exposed in Santa Clara Valley and in San Fernando Valley, where it rests unconformably upon the Modelo formation (upper Miocene) and unconformably below the Saugus formation (upper Pliocene and lower Pleistocene). It is entirely of marine origin, and contains a fauna belonging to the "base of the Pliocene in the standard time scale."² The Pico formation is oil-bearing near Newhall, Los Angeles County, and in some of the fields of the Los Angeles Basin.

Saugus formation (upper Pliocene and lower Pleistocene).—The strata comprising the Saugus formation of Hershey have always been included within the Fernando, although an unconformity had been recognized³ between these beds and the underlying beds, here called Pico formation. On account of the magnitude of this unconformity, which is widespread over southern California, this series of beds is now made a separate formation and given Hershey's name Saugus, the rocks being well developed in the vicinity of the town of Saugus, Los Angeles County. The strata are non-marine in the eastern part of Santa Clara Valley, but grade westward into strata deposited under marine conditions, where they contain a fauna of upper Pliocene and lower Pleistocene affinities. Strata correlated with the Saugus formation occur in the Los Angeles City district overlying the Pico formation; in Fernando Valley and on the south side of Oak Ridge they overlie unconformably the Pico; the same relations exist in the Los Angeles Basin where rocks of probably equivalent age are identified as representing the San Diego formation. The upper oil horizons in the Los Angeles Basin

¹ W. S. W. Kew, in paper by B. L. Clark, *Jour. Geol.*, Vol. XXIX (1921), pp. 608-9.

² W. A. English, *idem.*, p. 214.

³ W. A. English, *op. cit.*, pp. 206-7.

probably occur in this formation. The name San Diego formation has been used for many years for Pliocene and Pleistocene (?) strata which occur along the coast in the vicinity of San Diego. These rocks have been traced northward into the Los Angeles Basin district, where they have been definitely recognized at San Pedro.¹ It is highly probable that the San Diego formation is equivalent, in part at least, to the Saugus formation.

LATER PLEISTOCENE

San Pedro formation (Pleistocene).—This series of beds, which is typically developed in the vicinity of San Pedro, has been described in detail by Arnold,² who has divided it into two members, separated by an unconformity. The San Pedro occurs at many places in the Los Angeles Basin, resting unconformably upon beds of Saugus or San Diego age.

Terrace deposits (Pleistocene).—Numerous levels of terrace deposits which are older than the Recent alluvium are present along the southern California Coast and often extend inland as stream terraces. Although relatively little study has been made of the terrace deposits, it is probable that some of them are to be correlated with the upper part of the San Pedro formation.

¹ Ralph Arnold, "Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California," *Calif. Acad. Sci. Mem.*, Vol. III (1903).

² Ralph Arnold, *op. cit.*, 1903.

THE POSSIBILITIES OF OIL AND GAS IN SOUTHWEST VIRGINIA AS INFERRED FROM ISOCARBS¹

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INTRODUCTION

Years of search have failed to locate either oil or gas in commercial quantity in southwest Virginia. Slight traces of oil and some gas seepages have been found, but in the few cases in which drilling has been carried on, the reward has been no better than a meager showing of gas. One bore-hole in Wise County, 2,150 feet deep, has given a showing of gas and recently gas seepages have been reported from two shallow water wells in central Buchanan County. A study of the stages of carbonization of the coals of southwest Virginia offers opportunity to explain the apparent lack of oil and gas in commercial quantity in this region.

THE FIXED CARBON THEORY APPLIED TO SOUTHWEST VIRGINIA

The relationship of oil and gas occurrence to the carbonization of coals was first pointed out for the Appalachians by David White² in 1915 and thousands of subsequent applications of the hypothesis in all parts of the world have demonstrated its validity and value. In arriving at his original hypothesis, White noted that the rocks of the Appalachian coal field had been regionally affected by the enormous thrust forces exerted from the southeast, the degree of metamorphism being progressively less to the west and northwest. This degree is roughly indicated by the percentage of fixed carbon of the

¹ Published by permission of the Director of the United States Geological Survey and Dr. Thomas L. Watson, Director of the Virginia Geological Survey. The writer has prepared an article on the Possibilities of Oil and Gas in Wise County, Virginia, to be published in a report on the coals of Wise County, prepared under co-operative auspices of the Virginia Geological Survey and the United States Geological Survey, from which many of the data used in this paper have been extracted.

² David White, *Jour. Wash. Acad. Sci.*, Vol. V, No. 6 (March 1915), pp. 189-212.

coal on a moisture and ash-free basis which was noted. The percentages of fixed carbon were plotted on a map at the localities where samples were collected and lines, "isocarbs,"¹ were drawn connecting points of equal carbon percentages. These isocarbs show the progressive devolatilization of the coals toward the southeast and the corresponding increase in carbon in the same direction. White, in superimposing the isocarb contours on the oil and gas map of the Appalachian coal field, noted that where the coals were devolatilized to the extent of 70 per cent or greater of fixed carbon, oil does not occur, and that the easternmost limit of the oil fields is more nearly marked by the 65 per cent contour. In other words, where the rocks were sufficiently affected regionally by metamorphosing influences to devolatilize coals to 65 per cent of fixed carbon or greater, any oil the rocks may have previously contained was devolatilized and driven off. Later refinement and additional detail would place 63 per cent of fixed carbon as the probable limit of the occurrence of commercial pools of oil. Although 63 per cent may be taken as the "dead line" above which oil in all probability does not occur in commercial amounts, it is a fact that oil is not commonly found in commercial quantity above the 60 per cent of fixed carbon contour. Following White's pronouncement in 1915, observations in all parts of the world have firmly established this relationship of oil distribution to regional metamorphism.

White's law when applied to southwest Virginia offers an explanation for the lack of oil in commercial quantity in this region. Figure 1 represents southern West Virginia, southwest Virginia, eastern Kentucky, and an adjacent portion of Tennessee. On this map are shown the known oil and gas fields, the oil fields appearing in black and the gas fields in stippled patterns. The localities from which coal samples were collected for analysis are shown and isocarbs are drawn over the coal field portion of the map with a difference interval of 2.5 per cent fixed carbon. Where there are many sample localities the contouring of the fixed carbon ratios is better controlled than in areas where few samples have been collected. For this

¹ A term suggested by David White. First used in the literature by David Reger in a paper on "Carbon Ratios of Coal in West Virginia," *Trans. Amer. Inst. Min. and Met. Eng.*, Vol. LXV (1921), pp. 522-27.

reason the solid line is used to represent a well-controlled isocarb and a broken line to indicate lack of data or generalization.

The first and important feature to be noted in Figure 1 is the relationship of the eastern edge of the oil fields to the fixed carbon percentages of the coal. The 60 per cent isocarb practically marks the eastward limit of the oil fields. Little oil is found in this region southeast or east of this isocarb. The contours show clearly that

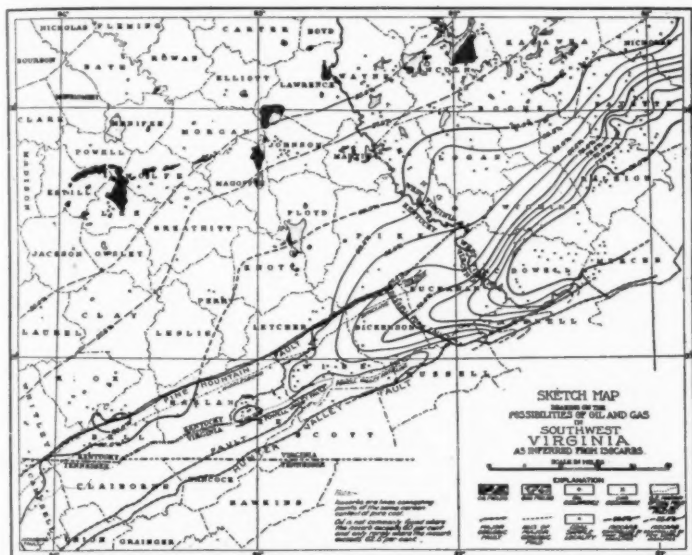


FIG. 1

in Buchanan, Tazewell, Dickenson, Russell, and eastern Wise County the coals have fixed carbon percentages of 65 and greater, and that the chances of oil occurring in commercial quantity in this region are negligible. In central, southern, and western Wise County the average fixed carbon percentage is practically 62.5 and here also the oil possibilities are reduced to a discouraging minimum. In Lee County, on the strength of only a small number of analyses, it appears the average fixed carbon ratio is close to

60 per cent, which, as far as the law of regional metamorphism is concerned, offers some slight encouragement for the occurrence of oil.

Closer inspection of the isocarbs shows a "southwestward plunging high" with an axis entering the coal field at McDowell County, West Virginia, about 20 miles due west of Bluefield and running through southern Buchanan and central Wise counties. A "low" is represented along the southeastern edge of the coal basin, the axis entering from Lee County and passing through southern Wise County and the coal-bearing portions of Scott and Russell counties. A high signifies a progressively higher percentage, in the carbonization of the coal, toward an axial line and a low a corresponding lower percentage. Thus as the carbonization is a direct function of the metamorphism undergone by the rocks of each particular locality, an isocarb map points out instantly the areas of greatly affected and little affected rocks.

The relationship of the isocarbs in Wise County shows that the coals of the Middlesboro syncline are more highly carbonized than those of the Powell Mountain field, north of the upturned rocks along Hunter Valley. It appears somewhat anomalous to have the less affected rocks of Wise County farther from the oil fields of Kentucky and the more greatly metamorphosed beds. A glance at the geologic structure of this region readily gives the answer. When the entire region came under the tremendous compressive forces exerted from the southeast the rocks of the Powell Mountain area were arched up like the bending of a bow and except for their position were little changed by their experience. The rocks of the Middlesboro syncline on the other hand were not relieved of their pressure by such a simple fold, and in consequence suffered regional metamorphism to a more marked extent than the rocks on Powell Mountain. The rocks of the Middlesboro basin were folded in several minor anticlines and synclines and were thus more intimately affected by the forces of regional metamorphism than the rocks on Powell Mountain. In both cases, however, the folding of the beds and the influence of regional metamorphism appears to have been sufficiently ample to

have dissipated any oil that originally may have occurred within the beds involved.

Considering southwest Virginia as a whole it will be seen that the highest rank coals occur in the northeast and the progressively lower rank coals occur to the southwest. This progressive carbonization of the coals shows clearly the relationship of faulting to regional metamorphism. The major faults affecting the metamorphism of the rocks of the coal field are indicated on the map. The faults are of the overthrust type, with low angle fault planes that dip from about 5 to 25 degrees to the southeast. It will be noted that the southeast margin of the Virginia coal field is nearly everywhere cut off by faults, called the Hunter Valley fault zone, and that the northwest margin of the field, including portions of Kentucky, is bounded, from Dickenson County to the southwest, by the Pine Mountain fault zone. Thus the greatest relief of pressure was obtained where the faults reached their maximum displacement and the coals were correspondingly less affected than where this relief of pressure was not given. The origin and mechanics of these major faults has been ably set forth by Wentworth¹ in his description of the Cumberland block, and will not be repeated here in detail. However, in general, he believes that the Pine Mountain fault first broke to the southwest and that it extended gradually to the northeast until reaching its present limit at the northwest corner of Buchanan County. If this is true, and the explanation appears entirely logical, it means that the coal-bearing rocks of Buchanan and Tazewell counties and the adjoining area of West Virginia have been under compression from the forces in the earth's crust acting from the southeast along the whole Appalachian front, for a far greater length of geologic time than the coal-bearing rocks southwest of Buchanan County. As pressure is unquestionably the chief factor in regional metamorphism it is apparent that where pressure producing forces have operated a long time the regional metamorphism would be more pronounced than where this pressure has been early relieved.

¹ C. K. Wentworth, *Jour. Geol.*, Vol. XXIX, No. 4 (1921), p. 351.

SUMMARY

Oil is rarely found above the 62.5 per cent isocarb and is not commonly found above the 60.0 per cent isocarb. The coals of southwest Virginia range in fixed carbon on the pure coal basis from about 60 per cent in Lee County to over 65 per cent in Buchanan County, for which reason it is believed quite unlikely that oil will be found anywhere in southwest Virginia. Gas does not appear to follow the isocarb theory with the same surety that oil does, and it is not safe to predict a minimum "dead line" for gas occurrence. In this region there is nothing to condemn its occurrence and there is a fair probability that it does occur in commercial quantity, but this can only be tested by the drill.

The influence of folding and faulting on regional metamorphism is well shown by the isocarb map of southwest Virginia and adjoining areas. Where blocks of the earth's crust have been elevated or moved horizontally, as a unit block, due to broad folds or faulting, the rocks within the block are not of necessity greatly affected, but where blocks of the earth's crust have been subjected to great pressures for long periods of time without appreciable relief, the rocks are greatly affected. No more delicate method has yet been devised for detecting this metamorphism and registering its range than the application of the isocarb theory.

GEOLOGICAL NOTES

THE WIGGLESTICK

Although to the oil geologist in this country it may seem difficult of belief, the wigglestick (witchwand) seems to be flourishing even to a greater extent in Germany than here. According to the accounts in wigglestick literature, the instrument was used to some extent in the German Army during the war and a German officer was officially attached to the Turkish Army in the capacity of wigglestick artist. There is an Internationaler Verein der Rutengänger (International Society of Wigglestickmen), an International Verein der Wunschelruten-forscher (International Society of Wigglestick Investigators), and a Verband zur Klärung der Wunschelrutenfragen (Union for the Explanation of Wigglestick Problems). Several small manuals and many minor articles on the supposed theory of the wigglestick, its uses and application, have been published.¹

After considerable difficulty in getting co-operation from the wigglestickmen, the German Geological Survey ran a series of tests under proper scientific control.²

Three wigglestickmen took part in the tests. A, who was an officer during the war and who had been certified by the International Society of Wigglestickmen, used an iron wand for the first determinations, a delta metal wand for correlation and an aluminum wand for the determination of depth. B, a less well educated man, who had worked for thirty-one years as a water-seeker, used a forked stick cut from a bush. C, a better educated man, who had worked for years as a wigglestickman, used no wigglestick for the first determination but received "positive radiations" in the left arm and "negative radiations" in the right arm. For corroboration, he used a pendulum which, he claimed, described curves for different substances.

Five different tests were run. In each case the wigglestickman was sent over a selected route accompanied by one or two geologists who

¹ Graf Carl v. Klinckowstroem, "Bibliographie der Wunschelrute," *Schriften des Verbands zur Klärung der Wunschelrutenfrage*, Heft 3, Nr. 1, and Heft 7, Nr. 2 (Verlag von Konrad Wittwer Stuttgart).

² "Zur Wunschelrutenfrage, Nr. 1: Die mit Rutengängern im December 1920 angestellten Versuche der Preussischen Geologischen Landesanstalt," *Preuss. Geolog. Landesanstalt*, Berlin, 1921.

charted the route and recorded the wigglestickman's observations. In the evening, a statement of the day's work was drawn up and was signed by the wigglestickman and the geologists.

The first test was to find water in an area underlain by impermeable Septarian clay in which springs are found only in sand and gravel lenses. The wigglestick indicated abundant water in the middle of the impermeable Septarian clay and made no distinction between the area underlain by sand and gravel lenses and that underlain only by clay. At one point, a weak coal "reaction" was given, although the clay is of marine origin and does not carry coal.

Second, a line across the Stassfurt salt dome ridge was tested for salt, potash, and brown coal. East of the salt dome, in an area where coal cannot occur, as borings show that the Diluvium rests directly on the Trias, A reported alternating coal and narrower coal-free zones for a distance of 450 meters and for the rest of the way, salt (Na and K) free zones alternating with narrower salt zones, although as a matter of fact, under much of the line a continuous salt deposit lies only a short distance below the surface. When crossing the salt dome, B reported potash, alternating with potash-free zones. In the area that contains no salt or potash and west of the salt dome he reported potash alternating with longer potash-free gaps. When over the brown coal basin, he reported brown coal absent.

The third test was a survey of the route across the faulted edge of the Magdeburg basin to determine the presence of potash salt and of faults. In only 11 cases out of 88, did A and B's reactions agree and then only partially. C reported much salt in the salt-free area but did not get as far as the salt area, and all of the salt "reactions" of A and C were in the salt-free Culm area. A plethora of faults was reported except where the strongly faulted edge of the Magdeburg basin is known to be.

The fourth test was to determine and delimit potash salt and brown coal deposits in an area underlain by Culm with the remains of a volcanic cover in the southwest and a marine Tertiary cover in the northeast. The area is therefore one in which the occurrence of potash salt or brown coal is out of the question. For a third of the way, A and B were in agreement in reporting salt and for half of this distance, C concurred, but elsewhere, the three were in hopeless disagreement. Both B and C reported long, continuous stretches of salt or of brown coal, but not at the same places on the route. A found only one small brown coal zone and only scattered salt zones.

The last test was to delimit a known salt dome, the Weitze-Steinforde dome. A reported broad salt-free zones and narrower salt zones indifferently on and off the salt dome. From the center of the dome, to a point about one kilometer away from it to the west, B reported a continuous salt zone; from the center to about the same distance off the dome to the east, alternating salt and salt-free zones. For the whole distance, C reported alternating salt and salt-free zones. No one of the three was able to delimit the dome even roughly and the three in no way agreed with each other in the reactions obtained.

The results of the tests speak for themselves, and in conclusion Beyschlag makes the comment that if there were something to the wiggelstick, its failure at times to register the presence of a substance might be explained, but that its brilliant registering of substances not present, could not be.

DONALD C. BARTON

THERMAL CURRENTS AS A FACTOR IN OIL ACCUMULATION

At the Shreveport meeting of the Association there was considerable discussion of the movement of underground waters and its importance in connection with the accumulation of oil and gas in certain structural features. One of the speakers advocated the occurrence of static bodies of underground water.

Some of the basic principles governing the movements of ground waters were ably discussed by F. H. King¹ and C. S. Slichter² twenty-four years ago. These papers are well illustrated. In them porosity, viscosity, capillarity, specific gravity, temperature, barometric pressure, diffusion, osmosis, solution, etc., are discussed at some length.

Unfortunately the problems under investigation by these pioneers were not associated with oil or gas and dealt with waters contained in alluvial deposits or in strata close to the surface. In their laboratory work they recognized the importance of temperature control and specially mentioned the difficulty experienced in maintaining uniform temperatures which would admit comparative results for practical purposes. No experiments were conducted by them which indicate the quantitative

¹ F. H. King, "Principles and Conditions of the Movements of Ground Water," *U. S. Geol. Survey, 19th Annual Rept., Part II, 1899*, pp. 59-294.

² C. S. Slichter, "Theoretical Investigation of the Motion of Ground Waters," *U. S. Geol. Survey, 19th Annual Rept., Part II, 1899*, pp. 295-384.

internal movement of water due to different temperatures at various localities within the experimental apparatus.

Since one of the primary teachings of elementary chemistry and physics is the extreme mobility of water, the writer claims no originality for the opinion here expressed. The innate instability of water precludes the possible conception of a static body of underground or surface water and logically supports the assertion that, theoretically, water is never at rest.

A water-bearing formation, especially if associated with folding, is found at varying depths from the surface and, as has been proved by observation, the temperature of the formation usually rises as its depth increases. The normal rise of temperature is approximately 1° for each 50 feet of increased depth below the surface.

It is a proved fact that thermal currents are created by differences in temperature at different points within a body of water. While the course of the major ocean currents is greatly influenced by winds and by the configuration of the continental coast lines, the major force which causes them is the difference in temperature of the connecting bodies of water in different portions of the ocean. The circulatory system of the Gulf Stream and the Japan Current prove conclusively that currents of this type are influential in turning over bodies of water covering extensive areas. Observation shows that a drop in temperature from 22° to 4° C. (71.6° to 39.2° F.) in 24 hours will completely turn over a body of surface water from 30 to 50 feet deep.¹ This same type of thermal current is illustrated on a small scale by the ordinary hot water system used for heating buildings.

Sub-surface temperatures of 150° F. are not uncommon in the vicinity of oil fields and sub-surface temperatures of 120° in and around oil fields have been frequently observed. Hence it is conceivable that the oil- and water-bearing strata which underlie the region may have been subjected to temperatures in excess of those mentioned above.

Assuming a symmetrical synclinal basin 3,500 feet deep, underlain by a sand of uniform texture and thickness, the sand outcropping around this basin at a uniform elevation and the original water contained in it of uniform salinity, we have the conditions which should be favorable to the presence of a body of static water as advocated in the Shreveport discussion. Under normal conditions and without the addition of rain-water which would dilute the salinity, the water in this sand near the outcrop would be cooler by virtue of its shallower depth than that

¹ Personal communication from H. Rosenthal, Chemist, City of Dallas, Texas.

in the bottom of the basin. This difference in temperature should in itself conceivably create thermal currents and cause a turn-over of the body of water within the formation.

Assuming natural conditions where the outcrop of the water-bearing sand is higher at one margin of the basin than at the other and assuming an addition of fresh water due to rainfall, water should issue from the lowest point on the rim of this formation. The fresh water would gradually dilute the salt water by diffusion and owing to the higher specific gravity of the water at the bottom of the basin, the fluid should move with less resistance around the outcrop and near the surface than it would in the deeper portion of the fold. This movement of fresh water in contact with the brackish water would set up cross-currents. At the zone of contact between the salt and fresh water other currents would be induced by diffusion, osmosis, and solution. By the introduction of geo-thermal temperatures within the basin, which may be due to increased depth and locally due to faulting, folding, chemical action, vulcanism, or metamorphism, thermal currents should be established sufficiently strong to create a marked movement of the fluid within the sand stratum. This movement should be accelerated in regions where oil or gas is associated with the water-bearing formation because if subjected to the same conditions these substances are more sensitive to compression and expansion than water.

The importance of circulating thermal waters in connection with the deposition of mineral deposits is recognized and has been discussed at length. While the importance of circulating waters in connection with the accumulation of petroleum is recognized and while the importance of metamorphism (the carbon ratio, etc.) is receiving due consideration, the importance of thermal circulation in the accumulation of oil and gas apparently has been entirely overlooked. Thermal circulation is an important factor which justifies thorough research.

Careful experiments, with apparatus duplicating as nearly as possible oil field conditions in which the effect of high and low temperatures properly controlled and introduced at various zones, can be observed, will throw some light on the importance of thermal currents in the accumulation of oil and gas. Discussion on this subject is invited and the citation of references to studies which may have been made along these lines will be of value.

LEON J. PEPPERBERG

DALLAS, TEXAS

SOME REMARKS ON THE CARE OF WELL SAMPLES

The writer has had occasion to visit a number of oil company offices, state surveys, and colleges during the past three years, and has made it a point to find out what becomes of the samples and logs sent to these various filing places by drillers and managers of oil wells. The information he has obtained reflects little credit on the geological profession. When samples were mentioned in the discussion of a well, the subject was persistently pursued until a search was made for the specimens themselves. The search often proved fruitless and many theories about "that cigar box" or "the tomato can I had on my desk" were propounded. One important bureau of information on deep drilling "didn't bother with samples" and the logs of the past decade or so which had been prepared and sent in by drillers and owners were disclosed in a heap in a wooden box. Some of the persons in charge of these dubious filing systems had been carefully trained in scientific methods and held positions of importance. Even in instances where samples were carefully preserved they were often in the same condition in which they were received except for an accumulation of dust and an occasional broken bottle.

Contrasting this condition with the methods which are used in other branches of geological work the prevailing custom is found to be primitive indeed. Consider the tender care which a paleontologist gives to a fractured fossil bone which he is removing from an excavation. It is mended, protected by a plaster cover, wrapped in cloth, labeled in various places, and in general given as much care as a priceless ornament from King Tut's tomb. When it arrives at the museum of its destination the wrappings are removed with great patience and a caution which is often amusing to the visitor. The matrix is removed in minute pieces and every fragment of loose bone is preserved and fitted into place—a process which sometimes involves weeks of time.

It is assumed that well samples are fully as important to the petroleum geologist as fossils are to the paleontologist and while it will be readily granted that the pressure exerted to speed up reports and produce results tends to a lack of technique which our fellow workers in museums have more leisure to develop, it is urged that the prevalent neglect of collections of well samples has often resulted in more haste and less speed.

It is time that the preservation of well samples is standardized. Some of the larger companies and some of the busiest consulting geologists have found time to insist upon a method in their offices. This Survey

(Michigan) has developed a method which is offered as a suggestion of a way to eliminate one of the most frequent obstacles to careful filing—a lack of space—and as a way to reduce the time of the labor to a minimum which will produce good results. Incidentally it has been found that the driller who visits the office is impressed by the care given to the samples he submits and greater care on his part and a more willing co-operation with office workers has resulted.

Samples are kept by the driller from as frequent intervals as possible. Every five feet is recommended as an interval. The sample is placed in a small cloth sack, and labeled as to depth on a paper tag attached by a cord. One sample in each shipment is labeled as to well number, section, township, and range. Upon arrival at the office these samples are washed. It has been found that the objections to washing samples are far outweighed by the advantages. The finest rock flour which is an undesirable artificial product is eliminated and with care the generally coarser clay particles and finest sand are preserved. The washing is done in a large test tube which is repeatedly filled with water and inverted until the particles settling from the upper part leave a clear ring of water. If after repeated washings no such ring is developed, the tube is set aside for a few minutes to settle or the sample is separated out by filtering, using filter paper and funnel. The great advantage in washing is the removal of rock flour from the mineral particles. Surprising results are sometimes obtained from what appears at first to be a homogeneous blue clay. After washing, the water is decanted and the sample turned out on filter papers which are marked with the depth of the sample and placed on pads of blotting paper. This insures quick drying and saves a great deal of time. When dry, the sample is placed in a two-dram vial, the excess material being turned back into the original package or thrown away if a chemical analysis is wanted for the unwashed sample. The vials are labeled by stickers and placed in order in specially constructed trays made of white-wood. The inside dimensions of the trays are $15\frac{1}{2} \times 2\frac{3}{4} \times \frac{3}{4}$ inches, the outside dimensions are $16\frac{3}{4} \times 3\frac{1}{4} \times 1$ inch. They are designed to give the smallest possible dimensions which are commensurate with the strength required. Each tray holds 27 vials and the margin is wide enough to indicate formation boundaries and names upon it. No covers are used but the trays are piled one upon the other in a steel filing cabinet. The economy in space is indicated by the fact that a recently reported well which is 2,627 feet deep and which furnished samples every five feet occupies a space 10 inches high and $6\frac{1}{2}$ inches

wide. The entire labor of washing, labeling, and filing one trayful of samples requires, with careful manipulation, about one hour. A well a thousand feet deep can be completely cared for in a day's time.

From the samples prepared in this way a detailed log is made and the first copy sent out is mailed to the driller or operator who has had the most important work of all—the saving of the samples.

LANSING, MICHIGAN

W. I. ROBINSON

PORPHYRY AT AMARILLO

At the semiannual meeting of the American Association of Petroleum Geologists in Denver, October 26–28, 1922, Wallace Pratt read a paper on the Amarillo district.¹ Recently Sidney Powers² has published a section showing that a buried felsite hill exists beneath the John Wray dome.

Subsequent developments have shown that the supposed felsite is in fact a sill, or sills, of rhyolite or trachite porphyry. These sills have been reported in the Amarillo Oil Company's Masterson No. 3, at 2,738 feet; in their Masterson No. 5, at 2,229 feet; also in their Bivins No. 3, at 2,372 feet; and in Greater Amarillo Oil Company's Masterson No. 1. All of these wells are large gassers. Only the last well at the time of the writer's visit, last November, had been carried deeper after encountering the intrusive rocks. Following is a log of the Greater Amarillo well. The writer was fortunate in being able to obtain several samples of porphyry, arkosic sand, quartz sand, and dolomite from this well, including a fragment of the dolomite encountered at 2,595 feet.

GREATER AMARILLO OIL COMPANY'S MASTERSON NO. 1, POTTER COUNTY, TEXAS

NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 20, Blk. G&M-3, Elevation 3,400 feet

Formation	From	To
Surface.....	0	15
Lime.....	15	35
Red clay (one-half bailer of water).....	35	240
Clay.....	240	250
Water sand (three bailers water per hr.).....	250	260
Lime.....	260	270

¹ Wallace Pratt, "Oil and Gas in the Texas Panhandle," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. VII (1923), pp. 237–49.

² Sidney Powers, "Reflected Buried Hills and Their Importance in Petroleum Geology," *Econ. Geol.*, Vol. XVII (1922), pp. 233–59.

Formation	From	To
Red clay.....	270	340
Water sand.....	340	348
Clay.....	348	355
Quicksand.....	355	365
Clay.....	365	395
Gypsum.....	395	470
Redbed (9 bbls. water per hr.), 2 hrs. later 2 bbls. per hr.; 2 hrs. later exhausted.....	470	475
Gypsum.....	475	495
Redbed.....	495	500
Gypsum.....	500	510
Brown shale.....	510	515
Gypsum.....	515	555
Clay.....	555	560
Gypsum.....	560	575
Blue shale.....	575	580
Brown shale.....	580	595
Water sand (salt water filled to 300 ft. level)...	595	600
Lime.....	600	630
Blue shale (caved badly).....	630	645
Quicksand.....	645	677
Clay.....	677	685
Lime.....	685	693
Red rock (cave).....	693	696
Salt and red rock.....	696	710
Red rock.....	710	745
Salt and red rock.....	745	1,195
Sand (sharp).....	1,195	1,235
Red rock.....	1,235	1,390
Lime.....	1,390	1,397
Gypsum.....	1,397	1,420
Salt (white).....	1,420	1,510
Lime (bottom 15 ft. very hard).....	1,510	1,550
Blue shale.....	1,550	1,563
Gas sand (estimated 4,000,000 cu. ft.).....	1,563	1,580
Red rock (total gas now estimated to be 40,000,- 000 cu. ft.).....	1,580	1,610
Gas sand (gauged 46,000,000 cu. ft.).....	1,610	1,625
Red rock.....	1,625	1,637
Gas sand (additional flow—not estimated)....	1,637	1,650
Red rock.....	1,650	1,680
Blue shale (more gas).....	1,680	1,685
Red rock.....	1,685	1,700

Formation	From	To
Gas sand (more flow of gas).....	1,700	1,712
Red shale.....	1,712	1,718
Blue shale.....	1,718	1,768
White slate.....	1,768	1,775
Blue shale.....	1,775	1,785
Lime.....	1,785	1,792
Red rock.....	1,792	1,797
Sandy shale.....	1,797	1,820
White lime.....	1,820	1,860
Sand (showing oil and gas).....	1,860	1,870
White lime (additional gas, estimated at 30,000,- 000 cu. ft., cased out).....	1,870	1,920
Gas sand.....	1,920	1,935
Porphyry.....	1,935	2,145
Sand, arkosic, immense gas, no test of amount..	2,145	2,185
Porphyry.....	2,185	2,190
Quartz sand, immense gas, no test.....	2,190	2,225
Porphyry.....	2,225	2,328
White lime (dolomite).....	2,328	2,390
Porphyry.....	2,390	2,415
Gray lime (dolomite).....	2,415	2,430
Quartz sand; estimated 60,000,000 gas.....	2,430	2,450
Gray lime (dolomite).....	2,450	2,470
Quartz sand.....	2,470	2,475
Gray lime (dolomite).....	2,475	2,510
Porphyry.....	2,510	2,580
Quicksand containing gas, immense quantity, amount unknown.....	2,580	2,595
Gray lime (dolomite).....	2,595	2,605

The writer submitted the samples of porphyry to several authorities on rocks and minerals. Dr. F. M. Van Tuyl, professor of geology at the Colorado School of Mines, examined samples of porphyry from Bivens No. 3, A. L. Company's Masterson No. 3, and the Greater Amarillo. He reported the rock to be a rhyolite porphyry, or trachite porphyry. To quote: "Numerous feldspar phenocrysts appear in the samples. However, no crystals of quartz were observed. If such crystals are present, they are microscopic in size." Lacking apparent quartz, he is inclined to call the rock trachite. Continuing Mr. Van Tuyl's statement:

The thicker sills which cooled slowly show the larger phenocrysts. The lower sills are thin and more dense. They are believed to have been intruded from the same magma as the coarser rock. In view of the fact that the cuttings

of the intercalated layers of igneous rock do not possess fragments showing the vesicular structure characteristic of lava flows, they are believed to represent intrusive sills. The fine texture of the samples suggests, but does not prove, that the lava solidified not far below the surface. There is likely to be an unconformity somewhere between the surface and the top of the uppermost sill.

The writer has no doubt that there are many interformational unconformities within the series. Based on fossil evidence, it has been determined that the series at Amarillo belongs to the Permian. Mr. Pratt's subsurface map suggests that probably a subsurface fault of fully 1,500 feet downthrow on the southwest exists on the southwest flank of the John Wray dome—between its crest and the Tuck-Trigg and White Park wells. It is suggested that the subsurface fault system and the igneous phenomena are associated, and, further, that many of the abnormal conditions at Amarillo may, in large part, be explained by the presence of the igneous rock. It seems possible that porphyry sills may also be found at deeper horizons at the Four Six dome. It is also possible that the folds are laccolithic in origin. The structural situation may be related to the Wichita-Arbuckle Mountain line of weakness.

Vast volumes of gas have been developed in the numerous wells drilled on both the John Wray and Four Six domes, from the Prairie Oil and Gas Company Lyman and Balfour well in Sec. 10, Blk. 9 G.M. Survey, Hartley County, Texas, west to Tipton *et al.* McConnell No. 1, Sec. 201, Blk. 3, I.&G.N. Survey, Carson County, Texas, east—a distance of sixty-five miles. It has been suggested that gas may be developed without interruption within that interval. The writer believes that this is quite probable.

Gas alone has been developed on the John Wray dome. Five oil wells have been brought in on the flanks of the Four Six dome. They are (1) Gulf Production Company Burnett No. 2, Sec. 106, Blk. 5, I.&G.N. Survey, Carson County, Texas; (2) Silk *et al.* Burnett No. 1, Sec. 93, I.&G.N. Survey, Carson County, Texas; (3) Texas Company Burnett No. 2, Sec. 114, I.&G.N. Survey, Carson County, Texas; (4) Gulf Production Company Dial No. 1, Sec. 90, Blk. 82, Hutchinson County, Texas; and (5) Whittington No. 1, Sec. 82, N.&T.C. Survey, Hutchinson County, Texas. The first three wells form a group on the northeast flank of the Four Six dome. These, with the fifth, obtained oil at a common horizon below the Big domolite—at an average depth of 3,000 feet. The Whittington well is the latest to be developed. It is impor-

tant in that it is located fully ten miles from the group and on the northwest flank of the Four Six dome. All are reported to have capacity of from 250 to 500 barrels. The Dial obtained oil within the Big dolomite at 3,080 feet, testing 75 barrels on the pump. All the wells are pumpers.

The oil, in each case, is said to rise only about 2,000 feet in the wells. The gas, at whatever depth found, from the Prairie well to the Tipton, whether it be on the John Wray or the Four Six domes, at 1,700 feet or at 3,000 feet, has a subnormal pressure of about 470 pounds. This uniformity of pressure is scarcely a coincidence. Doubtless the whole gas productive area is directly connected—one great reservoir. Mr. Pratt, in his paper, called attention to this condition.

Gas at 1,700 feet depth ordinarily has about 600 to 700 pounds pressure; at 3,000 feet it has around 1,200 pounds, dependent, of course, on the head of water transmitting the pressure. Water has a pressure of 44 pounds for each 100 feet of head.

The gas is largely found within the Big dolomite. It evidently occupies crevasses or caverns—all connected. The size of the well is directly dependent upon the diameter of the hole drilled and upon the size of the cavern pierced. Mr. Pratt called attention to the fact that in one case, on the Four Six dome, a well flowing wide open caused the closed pressure of a well fully three miles distant to drop from 470 to 165 pounds. Also, that successive gas volumes encountered in drilling were not cumulative. For instance, two discoveries of 5,000,000 cubic feet, instead of resulting in a total production of 10,000,000 cubic feet, as experienced under ordinary conditions, would result in but 5,000,000 feet. In case these are followed by a 40,000,000 flow, the well will yield but 40,000,000.

The oil of the area coagulates at around 50° F. and seemingly contains an excess of wax. It is at once suggested that the peculiarities may be attributed directly or indirectly to the igneous phenomena. The writer was recently informed by Mr. W. E. Wrather that at the Fayette gas field, in Arkansas, a similar subnormal gas pressure exists. It is suggested that water, which ordinarily transmits to gas its head pressure, is lacking in quantity sufficient to fill the available space, and thus has not a normal head. Lacking normal head, one must suppose that there is no present point of water intake; that the gas-bearing strata at Amarillo do not reach an outcrop. The writer has considerable familiarity with the adjacent regions westward and northwestward along the mountains, and has seen no such series exposed.

It is possible that when the igneous rocks were intruded the limestone was dolomitized by superheated, rapidly circulating waters. Additional space was created; and the gas was expanded to fill it. It is suggested that the gas now occupies a reservoir three times that existing under normal conditions.

It is possible that the gas accumulated after the intrusion; also, that the gas and oil, in part, at least, were distilled from their parent rocks at the time of the intrusion. The writer is of the opinion that in some instances at least the heat of an intrusive, where moderate, has rather been beneficial to the distillation of oil or gas, than destructive.

The peculiar character of the oil may be attributed to the fact that many of the more volatile constituents have been driven off by heat, and the wax thus concentrated. The oil is found in arkose material—angular granite pebbles, largely feldspar—probably originating in some adjacent buried hill. The writer does not believe that the oil exists primarily within this material, but it may have a deep-seated source, perhaps one laterally removed from the present place of accumulation. One well suggests such a source—the Prairie Oil and Gas Farwell, Sec. 37, Blk. 21, C.&S. Survey, in Hartley County, reaching the Big dolomite at 3,425 feet. At 5,000 feet it was in lime, water alone being reported. No other well in the district has gone so deep. In the field proper the Big dolomite has a maximum thickness of approximately 700 feet. The log below 4,100 feet reports slate and black lime. It is suggested that these may be rocks much older than those producing the gas and oil within the field proper. They may also be the source of these commodities.

The tendency of the oil to solidify at a relatively high temperature renders it difficult and expensive to handle, and correspondingly affects its commercial value. Doubtless considerable oil will be developed on the Four Six dome and possibly elsewhere in the area. So large a productive gas area has perhaps never before been developed. Because of the evident fact that one great reservoir exists, it is the judgment of the writer that a minimum of wells should be drilled. One well, located on the crest of each large dome, should practically drain the gas.

THOMAS S. HARRISON

DENVER, COLORADO
July 1, 1923

DISCUSSION

COLIN C. RAE'S "ORGANIC MATERIAL OF CARBONACEOUS SHALES"¹

It is refreshing to find a real new idea on the origin of oil so well presented as in Colin C. Rae's "Organic Material of Carbonaceous Shales." Fortunately for the idea, the organic matter of carbonaceous shales, including the "kerogen" of oil-shales, is of such hopelessly indeterminate chemical character that for a long time it will be impossible to disprove Rae's hypothesis that the stuff is essentially an altered mass of ulmo-humic acids precipitated by salt water. On the other hand there is little likelihood that we will soon find definite proof in favor of the idea, which accordingly seems destined long to remain a plausible working hypothesis to be kept in mind.

The expression "ulmo-humic" I should prefer to avoid because these acids are of such indefinite character. Their molecular structure remains wholly unknown. Nearly all colloidal organic matter suspended in fresh water is precipitated by the same salts that coagulate ulmo-humic acids. These acids are supposed to compose the greater part of the organic matter carried to the sea by rivers, but since their identification is uncertain, we must for the present admit that we do not know just what their percentage is. In other words we are using the word "ulmo-humic" with about the same degree of indefiniteness with which we use the word "kerogen." Some more general expression like "colloidal organic matter" would be safer, but this is a minor point.

The "humic acid theory," if I may so abbreviate it, may be applied to the origin of certain types of oils—say to the asphaltic oils—without forsaking the idea that other oils, such as the Pennsylvania oils, may be derived from quite different material, animal fats caught on clay particles, vegetable waxes, etc. Petroleums vary so greatly in constitution as to indicate considerable difference in source material as well as in temperature, pressure, and other conditions of formation. No one limited theory can be expected to cover the ground. It is therefore pleasing to find that Rae presents his idea as a suggestion for research, rather than as a theory of the origin of petroleum, which, however, it is bound to become.

A little doubt possibly may be cast on the "humic acid theory" by the fact that the "first intermediate substance" obtained by heating California oil-shales and extracting with solvents, gave McKee and Goodwin² a waxy substance which is said to have contained no combined oxygen. This single determination is all the information now available on this point. The same

¹ *Bull. Amer. Assn. Petrol. Geol.*, Vol. VI (1922), No. 4, pp. 333-41.

² *Quar. Colo. Sch. Mines*, Vol. XVIII, No. 1 (January, 1923), Suppl. A, p. 21.

writers found only 3.79 per cent of organic oxygen in fresh Colorado oil shale, and do not mention oxygen in their ultimate analysis of the "intermediate product." Of course it is possible that the original material may have been "ulmo-humic acid" and may have lost all its combined oxygen by natural decomposition and by the heating that preceded extraction with solvent. Still one would expect some combined oxygen to remain from the ulmo-humic acids, as in lignite. Franks and Goodier¹ failed to find any fatty acids or their esters in Colorado oil shale or in extracts therefrom.

Some observations may be made that seem to favor Rae's idea. For instance, in many places much of the Maricopa shale (Monterey) of California is not diatomaceous earth but chert. I have seen no petrographic study to determine whether the chert is reworked silica of diatomaceous origin or silica deposited from colloidal suspension in the sea-water. The latter origin, if proven, would be a point in favor of the idea. Phenomena of bedding, of replacement, etc., should decide the point.

An almost identical case is presented by the Mowry "shale" of Wyoming, which is really an impure shaley chert. My studies in the field and with the microscope have convinced me that the cherty and horny Mowry "shale" is the result of primary precipitation on the sea-bottom of colloidal silica with much organic matter and other sediment. The impure "chert" is perfectly bedded. It lacks botryoidal and concretionary structures, and there are no replacement phenomena such as characterize cherts derived by the segregation of silica previously disseminated in limestone. There are a few spicules of Radiolaria but no diatoms. Below the Mowry is the Thermopolis shale, 500 to 1,000 feet of jet-black, fine clay shale, also very rich in carbonaceous material, and practically devoid of fossils. One or both of these formations, for various reasons, seems the probable source of the oil in the Wall Creek sands, which immediately overlie the Mowry. Since Rae shows that the rivers carrying the most organic matter to the sea are also the rivers carrying the most silica, both in colloidal form, the fact that the Cretaceous oils of Wyoming are associated with the Mowry "shale" becomes significant.

Of similar significance is the association of the Appalachian oils with the Devonian black shales, which are characterized by a scanty fauna of dwarfed forms. The stunting of the organisms is thought to be due to high salinity of the water. Likewise, in Portuguese West Africa, I found abundant evidence that the oil had originated in calcareous rocks at the base of the Cretaceous strata, in a horizon characterized by local oolite and by a stunted fauna of diminutive bivalves, gastropods and ammonites, all suggestive of highly saline waters.

My previous view has been that the high concentration of these waters preserved the soft parts of organisms against decay, thereby promoting their accumulation in quantity adequate to make commercial deposits of oil. Rae's

¹ *Ibid.*, Vol. XVII, No. 4 (October, 1922), p. 4.

idea seems a little more pertinent, that high salinity promotes precipitation of colloidal organic matter carried in by rivers. It does not weaken the idea that the organic matter may have been preserved by the concentrated water. Yet it gives a more likely source for the organic matter, inasmuch as the water was not suited to support abundant life.

Under Rae's hypothesis the ideal conditions for the deposition of oil-forming material are such as prevail on the drainage of the La Plata and the Amazon, namely, a broad stretch of low country, warm and moist, covered by vegetation, but draining into salty seas. These conditions, except for doubt concerning the composition of the local seas, were realized in the eastern United States in the Devonian and early Pennsylvanian: they prevailed in the Rockies in the early part of the Upper Cretaceous; in California in the late Upper Cretaceous, in the Eocene and in the Oligocene; and on the Gulf Coast, through most of Cretaceous and later time. In Louisiana there is indication of highly concentrated water only in the anhydrite beds of the Lower Cretaceous (Trinity). In most regions there is little indication of the salinity of local seas and this factor often will have to be neglected. Such observations may find application in the study of the geologic columns of other regions in seeking the probable source of oil.

CHESTER W. WASHBURN

REVIEWS AND NEW PUBLICATIONS

Geology of the Tertiary and Quaternary Periods in the Northwest Part of Peru.

By T. O. BOSWORTH, with an account of the Paleontology by HENRY WOODS, T. WAYLAND VAUGHAN, J. A. CUSHMAN, and others. MacMillan and Co., 1922. 434 pages.

In these days when interest in South American geology is being stimulated by all manner of scientific expedition and pioneering investigation, a book such as this one cannot fail to attract large attention. It covers a field in which very little has hitherto been generally known, and presents facts of the sort it is most desirable, at least from the viewpoint of the geologist, to have known. It is an important contribution to the geology of western South America.

The book, which deals with the coastal strip of Peru between Tumbes and Payta, is separated into five parts. Part I deals with the structure and stratigraphy of the Tertiary formations; Part II, with the paleontology of the Tertiary formations; Part III, with the Quaternary geology; Part IV, with desert conditions and processes in the Tumbes desert; Part V, with the petroleum of the region.

Part I consists of a description, with maps, of the Tertiary formations of the region, which the author differentiates as follows:

Age	Formation	Thickness
Miocene	Zorritos formation	5,000 feet+
Upper Eocene	Lobitos formation	5,000 feet+
Middle Eocene	Negritos formation	7,000 feet+

The ages of the formations have been determined by the paleontologic work presented in Part II of the book. The series consists of clay shales, pebblebeds, and sandstones, and the three units are differentiated largely on paleontologic grounds. The Negritos formation is described in considerable detail, the Lobitos in less detail, and the Zorritos formation is treated very briefly.

The Tertiary rocks of the region are crossed by an elaborate network of faults which greatly complicates the structure and makes difficult the unraveling of a complete stratigraphic section. Under desert erosion the tilted blocks of shale and sandstone stand out as prominent topographic features, and it is possible in many places to follow the network of faults with the eye. Very detailed study is necessary for a correct understanding of the regional geology.

Part II contains systematic descriptions of fossils collected by the author. The Negritos formation yielded 65 species, predominantly Mollusca, which show it to be Wilcox and lower Claiborne (Eocene) in age. The 30 species found in the Lobitos formation show it to be upper Eocene in age. Foraminifera are the most distinctive fossils from the Lobitos. Only 9 species are reported from the Zorritos formation, which is Miocene in age.

Part III is a highly interesting account of the Quaternary geology of the region. Four principal oscillations of the Littoral are definable, each consisting of a subsidence, with marine transgression, and an uplift carrying the newly-formed beds above sea-level to form a "tablazo" or raised sea-floor. The author has called these oscillations, beginning with the earliest, the Mancora, Talara, Lobitos, and Salina episodes. Each is represented by its tablazo and all save the Salina show the cliffs marginal to the succeeding seas. Breccia fans and tablazo deposits yield a history of recent geologic occurrence that is told very clearly and with proper stress on points of true scientific interest. Cross-sections and block-diagrams make exceedingly clear all that the author wishes to present. However, the author's estimate, on p. 259, of 5,000,000 years as the minimum length of the Quaternary period, will cause a raising of eyebrows by many who have a basis for holding opinions on the length of recent geologic time.

Part IV is devoted to a description of desert conditions which is extremely valuable to the student of stratigraphy in that it gives a very definite set of criteria by which the results of certain desert processes can be recognized. The Desert of Tumbes is a true desert, and it affords unusual opportunity to observe the work of sun and weather in a region where rain falls about once in thirty years. The author's description of the work of wind, water, and sun in the desert, and particularly his observations on wind erosion and dune formation, are of great value and interest to any geologist. In this part, too, excellent photographs and diagrams add concreteness to the descriptive word.

Part V is concerned with the occurrence of petroleum in the region. The part begins with a repetition of salient facts already given in preceding parts, a feature which emphasizes the separate character of the parts and the mechanical way in which they have been thrown together. The history of the fields is given, and a brief account of each. The Zorritos, Lobitos, and Negritos fields are the important ones. The description is limited, for commercial reasons, to general facts, and much that might make this part interesting has thus been omitted. The oil occurs in the Zorritos, Lobitos, and Negritos formations, and is of fairly high grade. The geology of the oil fields is unusual; the block-faulting in the Tertiary makes the occurrence of the oil very irregular and difficult to predict, and the extreme intricacy of the structure gives rise to marked difference in the volume and kind of production among wells located very close to one another. As a result of the broken character of the ground, the production is scattered, and the yield of individual wells small, as opposed to the concentrated, high individual production ordinarily characteristic of anticlinal accumulations. The author thinks the oil probably originated from vegetable matter rather than animal, because of the abundance of carbonized vegetable remains in oil-bearing zones and because the organic animal matter at the shore, where most of the beds were deposited, was largely destroyed before it could have yielded oil. This matter, however, is probably subject to argument.

In two major points the book might have been made much more valuable. The first concerns the author's disregard of previous work in the region, and the second the plan of the book.

At the beginnings of the two sections on stratigraphic geology the author calls attention by footnote to the work of Grzybowski and that of the *Cuerpo de Ingenieros* of Peru, but he gives no further detail and does not relate any of the facts he presents to those presented by the workers who preceded him. With the account in this state, the geologist who wants to study the region through the literature is likely to be confused. One who is familiar with the ground can correlate most of Bosworth's observations with those of Grzybowski and others, and is in a position to judge the relative merits of statements which conflict to a serious degree. The general reader, however, must be at a loss to understand the complete reversal of Grzybowski's stratigraphy presented by Bosworth, and particularly so because both writers used paleontologic means to determine the ages of the formations. Bosworth's work, studied in comparison with that of Grzybowski, shows that the "Pliocene" Payta formation and the "Oligocene" Ovibio formation of Grzybowski do not exist, and that the region south of Cabo Blanco, instead of containing Upper Miocene and Pliocene beds, contains Eocene formations. Bosworth's failure to point out and explain at least briefly the salient features in which his work differs from that of Grzybowski seems lamentable to those who know something of the region, and can see that Bosworth is undoubtedly correct in most of his deductions. His disregard of Grzybowski is further unfortunate as far as the formations of the Zorritos region are concerned, for there Grzybowski is in the main correct. He has defined the Talara, Zorritos, and Heath formations—all of which are ignored by Bosworth, who lumps the Zorritos and Heath into his Zorritos formation (without warrant for doing it; they should be separated) and thus takes credit for a name not originally his, leaves "in the air" another name already validly proposed, and gives no explanation of why he did it. The student who has noted the complete upsetting of Grzybowski's stratigraphy in the country about Payta and Negritos may well wonder, when he turns to the Zorritos district, what the Heath and Zorritos of Grzybowski mean, and Bosworth's work does not give the facts that would make things clear. It is not the purpose of the reviewer to magnify the importance of Grzybowski's work, which is full of mistakes and thus untrustworthy, but to deprecate Bosworth's failure to relate his work to that already published on the region.

In this connection, too, it is unfortunate that Bosworth has used the name Talara, proposed by Grzybowski for a Tertiary formation, for one of the Quaternary tablazo deposits, and also that he has duplicated in similar fashion his own name Lobitos, which he applies to a Tertiary formation and also to one of the tablazo beds.

In other words, Bosworth has failed to utilize both the material and the opportunity to revise and clear up for the geologic public the stratigraphy of the region, and has left the matter in a state which makes necessary further

published statement before the literature on the area can have absolute informational value.

It will be regretted by those interested in the region as a whole that the author did not study in more detail the relationship of the formations of the Zorritos field to the Lobitos formation. In the northern part of the area Bosworth's Zorritos formation consists of two larger units, the Zorritos and Heath formations of practically all other students of the region. To one who knows the Zorritos region it seems likely, from Bosworth's description, that the upper part of the Lobitos formation is the same as the Heath formation, the lower shale of Bosworth's Zorritos. The bulk of the 5,000 feet which Bosworth claims for the Zorritos is in this shale, and it seems likely that his thickness of the Zorritos is highly overestimated. He mentions the possibility of an unconformity between the Lobitos and Zorritos formations, without any evidence for it, and on the basis of that possibility says that "it is not improbable that in some parts of the area the actual depth of the Tertiary accumulation attains to 20,000 feet." It is the belief of the reviewer that this figure is much too large.

The plan of the book suggests more a series of separate papers than a well-knit unit, and at least for the historical geology the plan is not wise. Parts I and III should be joined together, and Part V should be better related to them. As the author has separated them there is not only a discontinuous aspect, but also much needless repetition. The subdivision of the book into 76 chapters, some of them barely a paragraph in length, is not to be commended. Many, if not most, of the chapters should be paragraphs or other smaller divisions under more comprehensive headings. One vital objection to this splitting up of the work is that it wastes space, and in a book printed as luxuriously as this, with large type and many illustrations, space is an important and expensive element. It seems that in this and other ways the book might have been made less costly, thus placing it in reach of more people of average means.

The author states in his preface that the Tertiary fauna found by him is larger than any other hitherto found or described from the South American continent. In this he has overlooked two important contributions; his 83 species are less than half as many as those described by Ortmann in 1903 from the Patagonian Tertiary, and Philippi in 1887 published descriptions of 470 species from the Tertiary of Chile and Patagonia.

The book is lavishly illustrated by photographs, sketches, diagrams and maps, all of which are good and most of which are of value in making the work clear. In fact, clearness is a predominant virtue of the whole work. Some of the photographs, however, serve little purpose, and the author's practice of putting his own name under every one taken by him (in some of which he himself appears) is hardly necessary. A single statement would have been enough to show that he took all not otherwise accredited.

Perhaps the most valuable feature of the work, and the one which is most effective in overshadowing whatever defects it has, lies in the fact that Doctor Bosworth has presented in tangible and interesting form exactly the kind of

information concerning geologic processes and the criteria for their recognition that is most necessary to the development of our science. His accounts of the Quaternary geology, and of the processes now going on in the desert and on the coast, are highly illuminating, and they represent the kind of geologic observation it is worth while to make and record. They are, after all, the marks which distinguish the man of scientific vision, and they play a large part in making this book the valuable contribution to South American geology that it is.

U. S. GEOLOGICAL SURVEY

EDMUND M. SPIEKER

Geologic and Technologic Work of the Soviet Council of Petroleum Industry

American geologists who keep abreast of discoveries in oil geology should not overlook the work which is being done and published by the Soviet Petroleum Administration in Russia. A part of this work is contributive to the subject; a part is unimportant but more or less interesting. The government administration of Russian oil fields naturally took considerable prominence in the Soviet organization, even in the early days of Bolshevism. Gradually a number of the geologists of the old Russian Geological Survey have been gathered—a matter of existence—with engineers, some of whom were attached to former oil companies, into organizations early known as the Main Petroleum and Main Oil-Shale Committees of the High Council of Public Economy. Very closely affiliated, if not essentially a part of this bureau, is the Mining Academy. The rector of the Academy and chief of the Soviet Petroleum Administration is Professor Ivan Goupkin, a geologist of the old régime, who will be remembered for his official reports on the Maikop and Grosny districts. Goupkin, by the way, was the oil geologist sent over by the Kerensky government in 1917 to study American oil fields and the American methods of development. Several other geologists and engineers who will be mentioned later will doubtless be recalled by various American readers. The purpose of this notice is merely to note the scope of operations of the Soviet Petroleum Administration, and to call attention, mainly by mention of titles, to some of its geologic publications, with brief reference to a few of those which may be of more interest to the geologist, especially if, like myself, he does not read Russian. Several of the publications are worthy of formal review or abstracting by some American geologist who has command of Russian.

In 1920 the two committees began the publication of a magazine entitled *The Petroleum and Oil Shale Industry*. This magazine, though ostensibly monthly, was in 1920 and 1921 issued four numbers in one at three-month periods. The paper and illustrations of the first volume (1920) are as poor as can well be imagined. The third issue (168 pages quarto), embracing the last four numbers of the volume, exhibits growing strength and expansion of the organization. Some of the articles, about fifteen in number, have titles in

English as follows: K. P. Kalitzky, "The Oil Deposits of Sookayebó, Province of Kazan"; E. I. Pistolkorss, "The Flow of Liquids through Pipelines in Connection with the Designing of Oil Pipelines"; A. D. Archangelsky, "A Sketch of the Oil Shale Deposits of European Russia"; two papers by V. K. Valgis and M. F. Stroonnikov on "The Drying of Oil Shales" and on "Halogenes in Oil Shales"; M. N. Rostomyan, "The Problem of the Industrial Utilization of Sapropel [oil shale]"; S. M. Visloukh, "The Spreading of the Botriococcus Sapropel in the Balkhash Lake"; N. N. Nagornov, "The French Oil Industry—A General Review of the Oil Shale Industry in All Parts of the World"; and, finally, an account of the work of the branches of the Petroleum Administration during current months.

Brief English abstracts indicate the geologic interest in Kalitzky's article, while that by Pistolkorss is a somewhat extended discussion of physical problems, with copious mathematical formulae. Kalitzky states that the oil at Sookayebó occurs in dolomitic limestone, the structure of which is depositional; that about half of the wells did not reach the oil-bearing horizon and that others were drilled close to the outcrop near the Volga. Conclusions are pessimistic. Most of the remaining articles relate to technology, the oil shale deposits of Russia, and the nature and treatment of sapropel, the mother substance of petroleum. Some of the articles are followed by short abstracts in poor English which, however, is better than none.

The first four numbers forming the first part of Volume II for 1921 are printed on several tones of unbleached paper of a grade lower than most wrapping paper in our country. It embraces 200 pages and some charts and tables. The following titles are selected: N. N. Smirnov, "The Flooding of the Baku Oil Fields"; I. V. Melnitzky, "The Grozny Paraffin Crude and Some Problems of Its Treatment"; K. P. Kalitzky, "The Baikal Petroleum"; A. N. Rozanov, "The Possibility of a Combined Production of Oil Shale and Phosphate in Different Places East of the Volga"; and V. M. Kovlozsky, "The Sapropelite Deposits of Kortcheva."

Much of the number is given to discussion of production and refining problems and review of progress in oil field development in other parts of the world, especial attention being given to the use of oil shale. In passing mention may be made of a short article on "The Prospects of the World Petroleum Supply." The translation of the article by G. A. Burrell, P. M. Biddison, and G. G. Oberfell on "Extraction of Gasoline from Natural Gas by Absorption Methods" is a forerunner of other translations of important papers to be distributed by the Petroleum Administration.

The second part, covering the middle four months (Nos. 5-8) of 1921 contains 300 pages and is considerably improved in appearance. Among the articles is one by S. S. Nemetkin on the "Evolution of Professional Opinion in Regard to the Hydrocarbon Content in Caucasian Petroleum"; articles (with English abstracts) by N. D. Zelinski, "Benzinization of Oil Products"; A. L.

Pokrovskaya, "Extraction of Benzol and Toluol from Naptha"; V. A. Obrutcheff, "Oil and Gas Deposits in the Kertch Peninsula"; S. I. Czarnocki, "The Oil Fields of the Southern Part of the Baku Province" (with English abstract); K. P. Kalitzki, "The Baku Archipelago"; B. V. Zvanziger, "Slate Mining in Russia"; and N. N. Dobrokhotoff, "The Combustion of Oil Shales in Gas Generators." Other articles relate to wooden pipelines, transportation problems, refinery questions, with discussions of plans for increasing the Russian production; of the different aspects of the petroleum industry and of the output of the different regions, and a review of the oil industry and development in other countries, including Colombia. The topics discussed in this issue are world-wide in range. This number includes a translation of Burrell, Seiberg, and Oberfell's "The Condensation of Gasoline from Natural Gas" and a translation of D. R. Steuart's "The Refining of Shale Oil." The oil shale part of the Soviet Petroleum Administration was during this period especially enthusiastic.

The Kertch region has been tested since 1864 with freakish results. Obrutcheff, after reviewing the stratigraphy and structure, with much regional data and some paleontological correlations, points to the practical certainty of deeper untested sands in the older Tertiary. Presumably the accounts of development and the production statistics given in this magazine are more detailed and fully as accurate as those issued from Soviet headquarters in the economic bulletin.

The third part of the volume for 1921 indicates some reorganization. It appears as representing jointly the Central Board of Petroleum Industry and the Central Board of the Oil Shale Industry under the general supervision of Goupkin and P. Yakoobov, the latter being also editor. It embraces over 218 pages, besides a fascicle of tables, graphs and other illustrations.

Articles that may be of interest to geologists in particular are those by D. V. Golubiatnikoff on the "Deposits in Northern Persia"; K. P. Kalitzki, "The Ukhta Oil-Bearing Region"; A. N. Rosanoff, "Bituminous Shale Deposits of the Yurezan River, Ufa Province"; and A. J. Gorboff on "Sapropelites as a Source of Petroleum"—an article (critically discussed in the succeeding one by Kalitzki) of considerable interest from the standpoint of petroleum genesis. Other papers relate to refinery matters, sociologic questions, chemistry, the investigations of oil shales, and the results of using Volga oil shales as fuel under boilers, and in heating apparatus, etc. Two or three articles concern the latter problem, which, on account of fuel famine, was of much consequence to Russia in the latter part of 1921. Oil shale engineers should take note of the equipment and processes described and illustrated in these numbers.

Golubiatnikoff's article on northern Persia is an important contribution containing much original matter on the areal geology, stratigraphy, structure, and paleontology, and is accompanied by some detailed topographic mapping with cross sections and profiles.

The first fascicle (250 pp.) of Volume III, covering the first four months of 1922, is printed on bleached and calendered paper, the improvement being extended to the maps, tables, sections, and even the cover. It is issued by the Council of Petroleum Industry, commonly referred to, both in and out of Russia, as the "Azneft," an evidence of continued reorganization in the Soviet administration. It contains a somewhat notable article by Golubiatnikoff on the "Reserves of Oil-Bearing Lands in the Baku District," with English abstract giving estimates as to the area of proved territory, probable expansions, new sands, maximum capacity, and total reserves of the seven principal fields and several new areas of the district; one by Kalitzki on "The Producing Series of the Apsheron Peninsula"; a "geological survey" by N. M. Ledinoff "of Sviatoy (Holy Island)"; J. S. Salkind on the "Composition of Petroleum"; A. J. Himmelfarb, "Gas Deposits in the Northern Portion of Taurada Province and the Exploitation Thereof"; S. P. Gvosdov and N. N. Nagornov on "The Nature of Hydrocarbons produced by the Destructive Distillation of Weimarn Oil Shales"; several articles on the organization of a state petroleum industry; the chemistry of oil shale distillates; reviews of operations both in Russia and in foreign fields; production statistics and bibliographic notices relating to petroleum, oil shales, etc. Also we find in this number translations from American reports of the article by J. O. Lewis and W. F. McMurray on "The Use of Mud-laden Fluid in Oil and Gas Wells," of Ralph H. McKee and E. E. Lider's article on "The Thermal Decomposition of Shales" and of C. W. Botkin's "A Study of the Saturated and Unsaturated Oil from Shales." Most of the original Russian articles are accompanied by summaries written generally in clear and sometimes graphic English.

As with preceding numbers, there is a notable lack of advertising, which reflects an industrial and economic phase of Sovietism. There is, however, given a list of special publications by the "Azneft" to which attention will later be directed.

With the second instalment (Nos. 5 and 6) the publication becomes bi-monthly. This issue is mainly technologic, the principal matter of interest in the twelve articles being the problem of the vaseline and paraffin in the Russian oil and the manufacture of lubricants. These papers pertain to the transactions of the Refinery Section of the All-Russian Petroleum Congress, which met early in 1922.

Nos. 7 and 8, combined, include, first, eleven papers delivered before the geological section of the "First All Russian Congress of Oil Operators." Most of these papers concern the water sands of the different oil fields and the invasion of the oil sands by water, especially in the Baku and Grozny districts. The second group of papers touches mainly on the organization and administration under Soviet conditions of oil field development. One of these papers contains a draft of regulations to prevent invasion by water; another reviews the work of the geological and development section of the "Azneft," while a

third discusses the execution of the oil field investigation program. The third group of papers comprises a symposium on "The Development of the Oil Industry as Determined by the Available Reserve of Oil-Bearing Lands and Program of Work for the Coming Quinquennial Period." The nine papers which deal with the Ural, Terek, Kuban, Transcaspian, Ferghana, Ukhta and Volga districts are followed by a paper by S. I. Charnotski on "Methods of Calculating Oil Reserves and an Attempt to Apply the Same to the Grozny and Maikop Districts."

The next issue, Nos. 9-12 in one, is given to a discussion, embracing seven articles, on "Development of Oil Field Engineering in the United States, 1918-1922." To this review is appended a list of American patent publications on oil field engineering for the same period, and a list of American patents relating to mineral oils and chemical reagents. A supplement, issued separately, of about the same size, contains drawings and specifications of American patents relating to oil field and refinery equipment, processes and apparatus.

Beginning with Volume IV (1923) *The Petroleum and Oil Shale Industry* appears monthly. The ten leading articles in the first number are given mainly to discussions of the petroleum industry and its prospects under Soviet rule; advances in oil chemistry and oil technology and somewhat extensive reviews of papers by Joseph E. Pogue and the writer respectively on the future demand of oil products in the United States and on the distribution of the world's petroleum supplies. The interest in international petroleum problems, both industrial and political, is further evidenced by an extended article on political control of world oil supplies and by the discussions of the history and activities of companies like the Dutch Shell, Anglo-Persian, and Standard Oil. In much enlarged space the reviews and abstracts of the leading current publications of the world relating to oil geology and technology reflect the larger opening of Russia to foreign mails and the activities of the Committee of the American Research Council in forwarding scientific publications to scientists and scientific institutions in Russia. The results are very creditable. The issue is good book making, with the inclusion of some neat figures in the body of the text. It is especially valuable to Americans for the accounts, with statistics of production, of the work of the year in the principal producing regions of Soviet Russia, though it is to be regretted that the review by Goupkin of the industry under Soviet rule has no English abstract. In fact less attention appears to have been given to the preparation of English summaries. One, however, reviewing the problems encountered through necessity of using rich paraffin residues as fuel on railroads (due to the collapse of coal production) and the treatment employed in the utilization of paraffin crude, should be of interest to petroleum technologists.

Number 2, received in April, embraces ten articles, besides about forty pages of reviews and abstracts, and five pages of production statistics. The first paper is a review of the petroleum industry during the first quarter of the

operating year, 1922-23. The geological contributions include a "Description of the Geology of the Uchta Oil Fields," by D. V. Nalivkin; "On the Application of the Method of Radiometric Surveying to the Prospecting of Oil Deposits," by L. N. Bogojavlenski; and a third on "A New Oil Enterprise of the Name of V. I. Lenin, Situated on the Filled-in Gulf of Bibi Eibat (Baku) Region." The number contains two articles translated from English. A supplementary number, issued at the same time, under separate cover, of about 150 pages, is given to the production of drawings and essential specifications of American and English patents relating to refinery processes, drilling equipment, etc. One wonders what respect is given to foreign patents in Soviet land.

An activity of the Council of Petroleum that cannot fail to be of distinct value to the country and that reflects the character and outlook of the Administration, is the publication in Russian, mostly by translation, of books and memoirs relating to petroleum geology and oil field and technologic problems. Several such have already been mentioned as having been printed in the magazine. In 1921 there was issued a small volume by K. P. Kalitzky, a geologist of the old Geologic Committee, on "The Geology of Oil"; a translation of W. Scheithauer's "Die Schweltheere, Ihre Gewinnung und Verarbeitung"; and a pamphlet by K. E. Bogdanovitch comprising Part I, descriptive of deposits of petroleum and other bitumens. Another memoir, by S. E. Tcharnotzky, published in 1922, concerns "Methods of Calculation of Oil Reserves in Oil Fields"; also M. P. Soloveff, "Retort for Burning Shales"; and Russian translations of H. Potonié's volume "Die Supropelite"; Cunningham Craig's "Oil Finding," and Besychlag's "Neue und Alte Wege der Braunkohlen und Schiefer Verschwelung," the last two of which bear the imprint 1923. The Cunningham Craig translation is on good paper, but lacks nearly all illustrations. The Beyschlag volume contains cuts and maps and presents a moderately good appearance.

The Council announces as "soon to appear" translations of C. P. Bowie's "Oil Storage Tanks and Reservoirs" and his paper on "Extinguishing and Preventing Oil and Gas Fires"; F. B. Tough, "Methods of Shutting Off Water in Oil and Gas Wells"; A. W. Ambrose's "Underground Conditions in Oil Fields"; Dorsey Hager's "Oil Field Practice"; a report by V. M. Weber on "Field Geology"; and a map of the petroleum deposits of the Ural region. The Council lists as in preparation, translations of A. Campbell's "Petroleum Refining"; Hager's "Practical Oil Geology"; Johnson and Huntley's "Principles of Oil and Gas Production"; a Russian work by I. N. Glushkoff consisting of a "guide to oil drilling" and the report of the All-Russian Petroleum Congress.

It is noticeable that the interest in oil shale development appears to be less prominent in the later publications of the Council. All things considered, however, the record of the geological and technological branch of the Bolshevik

outfit is highly creditable to the struggling handful of geologists, virtually prisoners in the country, whose bread-tickets depend on their service to the ruling régime and who must have found some distraction, amid scenes of woe and industrial wreckage, in the pursuit of their special lines of investigation. The magazine is a necessary part of every petroleum library. It is hoped that some of the articles describing Russian fields or covering original investigations of interest to American petroleum geologists may later be made the subjects of special reviews or summarizations in this *Bulletin*.

DAVID WHITE

The Business of Oil Production. By JOHNSON, HUNTLEY, and SOMERS. New York: John Wiley and Sons, 1922. Pp. 259, figs. 30, map 1.

This book is planned primarily for those participating in the oil industry, such as the executives and officials of an oil company and independent oil producers, who have not been especially trained to deal with the office and field details. The topics discussed include the selection of regions for operation, leasing, organization, financing, development programs, some features of operation and office routine, taxation, and the future prospects of the oil industry. The oil and gas rights on federal and state lands in the United States and in other countries of North and South America are surveyed in brief. A short summary of the Mexican situation, originally printed in the *Bulletin of the American Institute of Mining and Metallurgical Engineers* for September, 1921, is reproduced. There is an appendix which includes a copy of the Oil Land Act of February 25, 1920, Regulations for the Operation of the Act, a Digest of Decisions and Opinions on the Act, and State Acknowledgments.

Although numerous articles on these and similar topics have been published from time to time in various magazines and journals, so far as the reviewer knows no previous attempt has been made to bring the best of such information together in one volume especially dedicated to the oil fraternity. The book most similar in scope is probably Pogue's recent work on *The Economics of Petroleum*, but there is little overlap between that and *The Business of Oil Production*. Certain topics of timely interest to investors in oil securities merit particularly careful study. Among them are: "Modes of Indirect Development," "Size and Scope of Oil Companies," "Financing of Oil Companies," "The Oil Company Prospectus," and "Cost of Producing the Oil." Illustrating the need of careful thought on such subjects, mention is made of the McKeesport gas boom of 1919, where a \$20,000,000 investment yielded a \$2,750,000 product.

One of the merits of the book is the stress laid on financial considerations, for many of the cost items incident to the production of oil and its products are commonly overlooked. This discussion should be of practical interest to those who are concerned with oil land values. In several places in the book the

reader's attention is especially directed to the need of expert advice in matters pertaining to geology, appraisal, and taxation. The same care, however, is just as necessary in the selection of methods of financing, development, operation, office routine, and marketing details.

Altogether the book contains material which should be of considerable value to those for whom it was prepared. A few typographical errors have crept in, but these are not serious. Page 260 is blank, although the material for it is listed in the table of contents and the index.

J. H. HANCE

Origin of Oil in Northern Mid-Continent. By FRANK C. GREENE. Oil and Gas Journal, May 17, 1923, pp. 18, 111, 112.

The author argues that the ultimate source of oil in northern mid-Continent fields is "black, fissile, non-sandy, 'slaty' shales," that these source beds are confined to a few well-marked horizons, and that oil from each was probably originally distinctive in character. He lays particular emphasis on the Chattanooga shale which is suggested as the source of oil in the Wilcox and Turkey Mountain sands, in the various "breaks" in the Mississippian limestone, and, where there has been much fracturing, in higher beds. Failure thus far to find oil in the Otoe region, and east central Kansas is ascribed to an absence of source beds. Oil in "shoestring" and other lenticular sands is ascribed to proximity of source and reservoir beds, together with reservoir forming conditions inherent to lenticular sands.

K. C. HEALD

Oil Shale of the Rocky Mountain Region. By DEAN E. WINCHESTER. U. S. Geol. Survey Bulletin 729, 1923.

The United States Geological Survey's recently published bulletin entitled "Oil Shale of the Rocky Mountain Region" by Dean E. Winchester, is a worthy contribution to the literature on oil shale. It gives the geologist and others interested in the oil industry what they have been looking forward to for a long time, namely, a single bulletin which outlines in brief, compact form the essential and worth-while facts pertaining to the oil shales of six states that contain important amounts of oil shale.

In this paper Mr. Winchester, who is one of the leading authorities in the United States on the subject of oil shales, describes in detail field and laboratory testing apparatus and methods of distilling oil shales. In another chapter the author discusses the physical and chemical properties, the distribution, and the general geology of the shales, and includes a compilation of the fauna and flora of the Green River formation.

The report gives detailed information on the oil-yielding shales of Colorado, Idaho, Montana, Nevada, Utah, and Wyoming. The geography, stratigraphy,

structure, generalized stratigraphic sections, results of distillation tests, and development work in the oil shale areas of these states are described with more or less completeness.

An additional important feature is a 60-page bibliography which enumerates 1,106 reports and articles dealing with oil shales, with names of authors and titles of papers, published before March 1, 1922. A copy of the regulations concerning oil shale leases which were approved by the Secretary of the Interior, March 11, 1923, is included in the bulletin. The bulletin is well illustrated and contains six maps, four of them of a detailed character.

The author estimates "that if 60 per cent of the total shale in northwestern Colorado existing in the ground as beds 3 feet or more thick and yielding at least 15 gallons of oil to the ton were treated in retorts, it would produce a total of 40,640,000,000 barrels (42 gallons each) of crude shale oil," with an ammonium sulphate yield of 400,000,000 tons. On a similar basis it is estimated that Utah will produce about 20,000,000,000 barrels of shale oil. Although these figures are probably conservative it must not be assumed that large amounts of shale oil will be easily and economically recovered in the future. Those interested in the oil shale industry must keep in mind that in recovering oil from shales a triple industry is involved, namely mining, oil recovery, and refining. This means the expenditure of several millions of dollars for each plant if the shales are to be handled at a profit. Mining, distilling, and refining on a large scale in the oil shale fields of the United States are not likely to materialize for many years. However the chemical engineering and the geological research work which are being accomplished in the study of oil shales are invaluable, and hasten the day when this new industry will be assured of success.

In addition to his own research work, Mr. Winchester has incorporated in Bulletin 729 a part of the work of other investigators of the United States Geological Survey. All in all, the bulletin is a worthy contribution to oil shale literature and will be well received by all those interested in this subject.

E. F. SCHRAMM

Petroleum Possibilities of Costa Rica. By A. H. REDFIELD. Ec. Geol. Vol. XVIII (1923), No. 4, June-July, pp. 354-81.

Those interested in the geology of Central America will find the short paper by A. H. Redfield, "Petroleum Possibilities of Costa Rica," a concise and accurate summary of much of the published data that deal with the geology of that country. Accuracy was insured by the author through consultation with T. W. Vaughan, W. P. Woodring, and J. D. Sears, of the United States Geological Survey—all of whom have first-hand information regarding at least parts of Costa Rica. The exposed sediments, which range in age from Cretaceous or early Eocene to Recent, are for the most part in the coastal plains

marginating a broad mountainous zone which forms the backbone of the region and is composed almost entirely of igneous rocks. Intrusives also pierce the sediments in many places, and there are large masses of plutonic rocks that may antedate the sediments. Wide areas are covered by extrusives, which make it difficult or impossible to appraise the potentialities for oil of these covered areas. The sediments in many places are complexly folded and strongly faulted by deformation that took place during late Miocene and early Pliocene time.

Indications of oil and gas are limited to a few scattered oil and gas seeps and a flow of gas encountered in a well drilled by the Costa Rica Oil Corporation (Sinclair) at Cahuita Point in southeastern Costa Rica.

A very valuable feature of the publication is a bibliography of forty-eight entries listing the most important published contributions to the geology of Costa Rica.

This paper might not be of great value to one thoroughly conversant with the rather limited geologic literature on Costa Rica, or who has reliable first-hand knowledge of the geology of the country, but it is the type of description that is needed by one who is not familiar with the literature and who wants to get a general picture of geologic conditions there and to learn where more detailed information may be had.

THE ASSOCIATION ROUND TABLE

CORRECTION

In Volume VI, page 524, sections 1 and 3, incorrectly numbered by the author, should be respectively 3 (from Roumania) and 1 (from Moravia).

REPORT BY THE PRESIDENT

The new president transmits greetings. He doesn't hope to be able to do the constructive work Bill Wrather did. It's not likely to happen again soon. But he'll give all he's got.

REGIONAL DIRECTORS

James H. Gardner, of Tulsa, has been appointed Regional Director for the Mid-Continent.

John R. Suman, of Houston, has been appointed Regional Director for the Gulf Coast.

Other regional directors will be appointed in the near future. If you have plans, criticisms, suggestions, or questions regarding Association affairs in your region, talk or write to your regional director.

EXECUTIVE ACTIONS

The executive committee, at meetings in Shreveport and Dallas, closely following the Shreveport meeting, took action regarding a number of matters referred to the committee by the meeting. Briefly stated, they are as follows:

California meeting: The committee voted to hold a mid-year meeting in Los Angeles (date later fixed for September 20, 21, and 22).

Election methods: The committee decided, tentatively, to hold next year's election under the system heretofore in use, changing, however, the nominations to the morning and the election to the afternoon of the second day of the meeting.

Secretary's salary and expenses: The regular salary of the secretary is \$600.00. The committee voted to pay an additional special salary of \$300.00 for the current year, and to pay the expenses of the secretary and such additional secretarial help as he needs to this year's mid-year and annual meetings. The secretary has heretofore had the right to reimburse himself for the expense of attending meetings, but Dr. Decker's interest in the prosperity of the Association has been such that he has never done it. The present executive committee hopes to insist.

Regional directors: The Shreveport meeting asked that consideration be given to the possibility of having elective regional vice-presidents. The present executive committee is unanimous in believing that the executive committee

as at present constituted is large enough (just try getting a decision from five widely-scattered men!). Possibly the desired result can be attained by the appointment of regional directors, these men to be the executive heads of the Association in their respective regions, to look after the affairs of the Association and the interests of its members therein, and to be the regional points of contact between the members of the Association, the public, and the executive committee. The committee voted to try this plan. Gardner and Suman have accepted appointment for the Mid-Continent and Gulf Coast respectively. Other appointments are pending.

Research committee: The executive committee responded to the urgent sentiment of the members attending at Shreveport by appointing what it hopes will be a permanent committee. W. E. Wrather was of course named as chairman; the choice was obvious, and inevitable as sunrise. Other members will be named later.

AND NOW

If you think something should be done, or undone, or redone, or if you think of some way to make the Association or its members better or more useful, let me know. And above all, *Come to California.*

MAX W. BALL

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma.

(Names of sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

Walter Bernoulli, Antwerp, Belgium

O. Fischer, E. Bloesch, Sidney Powers

Rudolf Branchli, Tulsa, Oklahoma

P. H. Reischer, W. B. Wilson, E. Bloesch

Carl St. J. Bremner, Berkeley, California

S. H. Gester, Carl H. Beal, R. E. Collom

Theodore Chapin, Tampico, Mexico

H. F. Nash, F. A. Herald, V. R. Garfias

Floyd C. Dodson, Fort Worth, Texas

H. P. Bybee, W. E. Pratt, F. H. Lahee

D. D. Finley, Washington, D.C.

L. R. Van Burgh, C. Z. Logan, J. R. Roberts

George M. Fowler, Salt Lake City, Utah

C. Max Bauer, A. A. Hammer, E. G. Robinson

- Robert M. Gawthrop, Tulsa, Oklahoma
O. M. Edwards, J. C. Ross, R. S. McFarland
Robert F. Imbt, East Stroudsburg, Pennsylvania
W. E. Pratt, Sidney Powers, D. R. Semmes
Harry R. Johnson, Los Angeles, California
R. P. McLaughlin, W. S. W. Kew, J. E. Thomas
Leonard W. Orynski, Abilene, Texas
S. H. Gester, E. D. Lynton, B. L. Laird
Max Reinhard, Geneva, Switzerland
E. Bloesch, Sidney Powers, O. Fischer
Howard N. Spofford, Tulsa, Oklahoma
R. S. McFarland, J. P. D. Hull, A. F. Crider
Dwight H. Thornburg, Tulsa, Oklahoma
W. Van H. Pellekaan, R. J. Davis, S. W. Wells
Van Court Warren, Los Angeles, California
Wayne Loel, Ralph Arnold, W. S. W. Kew
Edmund J. Young, Whittier, California
J. E. Thomas, W. A. English, E. D. Lynton
P. L. Henderson, Los Angeles, California
R. B. Moran, D. Fyfe, R. P. McLaughlin
K. H. Hunter, Pasadena, California
J. E. Elliott, R. B. Moran, D. Fyfe
F. C. Merritt, Los Angeles, California
R. P. McLaughlin, J. E. Elliott, J. B. Case
F. A. Morgan, Jr., Los Angeles, California
J. E. Thomas, R. P. McLaughlin, F. S. Hudson
V. C. Perini, Denver, Colorado
C. M. Rath, H. T. Morley, T. S. Harrison
H. B. Thompson, Los Angeles, California
R. P. McLaughlin, J. B. Case, J. E. Elliott
C. C. Thoms, Los Angeles, California
R. P. McLaughlin, J. E. Elliott, J. B. Case

FOR TRANSFER TO FULL MEMBERSHIP

- W. W. Patrick, Tulsa, Oklahoma
L. M. Neumann, R. H. Wood, A. W. Lauer
R. A. Steinmayer, New Orleans, Louisiana
A. McLeod, P. L. Applin, G. Kirby

FOR ASSOCIATE MEMBERSHIP

- William A. Barth, Aspinwall, Pennsylvania
R. H. Johnson, L. G. Huntley, R. E. Somers
Thomas W. Buzzo, Los Angeles, California
S. H. Gester, E. D. Lynton, B. L. Laird

- Frederick W. Haecker, Lincoln, Nebraska
E. H. Barbour, L. O. Whyman, E. F. Schramm
Raymond R. Hahn, Barnes, Pennsylvania
R. H. Johnson, L. G. Huntley, R. E. Somers
James N. Hockman, Norman, Oklahoma
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D. J. Wolff, Fort Worth, Texas
E. M. Closuit, D. Donoghue, L. P. Garrett

OBITUARY

ARTHUR EATON

Arthur Eaton died on May 5, 1923, in the Merritt Hospital, Oakland, California, following a major operation.

His work as a petroleum geologist has been so actively carried on in practically every oil producing state in the Union that he leaves a host of friends in the American Association of Petroleum Geologists and among the oil men generally throughout the country.

In the ten years since Arthur Eaton graduated from the University of California, he crowded a lifetime of tireless endeavor and achievements, and his name stands today among the great petroleum geologists of the United States. Space will only permit a brief review of his work and the writer feels helpless in trying to pay proper tribute to Arthur Eaton, the man.

As a boy, Arthur Eaton was greatly impressed by Elbert Hubbard's book, *Carrying a Message to Garcia*, and the influence of that book seemed to be the guide to him both in his studies and his work. His motto seemed to be, "Let no obstacle stand in my way." In fact he seemed happiest when fighting his way through the hardest storms, the roughest mountains, or the attempts of others to beat him in getting the data on any geological problem. His early years of hard work and his years of training on the university crew gave him physical strength that seemed unbreakable. He was tall and straight like an Indian and he was fearless in danger and tireless in work. Wherever Arthur Eaton has worked one will find the ranchers and farmers who remember him for his friendly way and his feats of endurance and the long hours he would spend in the field.

In his studies he was the same hard worker, always anxious to read and study what other geologists had written. He had a winning personality, a love of good sports, a kind and thoughtful loyalty to his friends, and with it all his guiding motto to get results no matter how great the obstructions to be overcome.

The American Association of Petroleum Geologists have lost a good, true friend, and a member whose work will always be a matter of pride to the Association and a credit to the profession of petroleum geologists.

Arthur Eaton was born in Wayne, Michigan, October 28, 1886. He was the son of Mr. and Mrs. James L. Eaton. His early boyhood was spent in Wayne, Detroit, and Ann Arbor. He came to California when seventeen years of age and for several years was employed by the Los Angeles Chamber of Commerce. A part of this time he assisted in the mining displays of the Chamber of Commerce at Atlantic City, and the Exposition at Portland, Oregon, and Seattle, Washington.



ARTHUR EATON

He entered the University of California in 1909 graduating in the college of Mines in 1913, specializing in geology. On graduating he was one of the honor men in his class. He was also a member of the Sigma Xi, Tau Beta Pi, and Theta Tau honor societies. He was a member of the Phi Kappa Sigma fraternity and was on the varsity crew of the university for three years, being captain in his Senior year. He spent his summer vacations in working in the mines in Nevada and California and on graduation went to work in the copper district near Ely, Nevada.

In 1914 he was a member of the Louderback Geological Party sent out by the Standard Oil Company of New York to investigate large areas in China and the Philippine Islands. This campaign lasted two years.

In 1916 on his return to the United States he was interested for several months in some important investigations in the oil fields of California and then moved to Denver, Colorado, and began work associated with Thomas S. Harrison as consulting geologist for the Midwest Refining Company. Later a partnership was formed with Thomas S. Harrison under the name of Harrison and Eaton and offices were opened in Denver, Tulsa, and Fort Worth for consulting work in geology.

In 1921 he went to New York City and became associated with James Darnell, specializing in taxation problems in oil and mining. In this new field he built up a splendid reputation for ability to determine the depletion of oil properties and the adjustment of oil and mining taxes.

In August, 1922, he was a delegate from the American Association of Petroleum Geologists to the International Geological Congress in Brussels. In February of 1923 he opened an office in San Francisco and planned to make his permanent home in California.

He was a member of the American Institute of Mining and Metallurgical Engineers and the American Association of Petroleum Geologists. His clubs were the University Club of New York, Pomonok Country Club, Long Island, Fort Worth Club, and Berkeley Country Club.

He was married June 12, 1916, to Emily Churchill, of Berkeley. She and his son, Arthur Eaton, Jr., and his daughter, Martha Eaton, survive him.

CLARENCE B. OSBORNE

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

W. W. RUBEY and H. W. HOOTS are working for the U. S. Geological Survey in the Black Hills region.

D. DALE CONDIT has recently changed his address to 12 Middleton Mansions, Calcutta, India.

C. W. SHANNON, F. M. BULLARD, and BESS U. MILLS have organized a Bureau of Geology with offices in Norman. The Oklahoma Geological Survey has been disorganized.

AMIL A. and FRANK B. ANDERSON have moved their offices from Denver, Colorado, and El Dorado, Kansas, to 304 Bitting Building, Wichita, Kansas.

RAYMOND C. MOORE is geologist to the government expedition which this summer is exploring the Grand Canyon of the Colorado. The party is proceeding by boat from Lee's Ferry, Arizona, to Needles, California.

RUSSELL S. KNAPPEN is teaching during the summer quarter at Leland Stanford, Jr., University.

CLIFTON S. CORBETT is doing geological work in Alabama.

K. C. HEALD, who gave a course in oil geology at the University of Chicago during the spring quarter, has returned to Washington.

KIRTLEY F. MATHER is geologist on a Government Survey party working in southeastern Alaska.

ALLEN C. TESTER is in Kansas on work for the State Geological Survey.

WINTRHOP P. HAYNES is chief geologist for the Standard Oil Company of New York in Europe. His address is 82 Avenue des Champs-Élysées, Paris.

W. R. CALVERT has moved from Salt Lake City, Utah, to 557 Metropolitan Theater Building, Los Angeles, California, to become president of the United States Refining Company and vice-president of the United States Royalties Company.

CHESTER M. CREBBS is no longer chief geologist for the Mexican Gulf Oil Company, and is now general agent for the Venezuela Gulf Oil Company, and is stationed at Caracas, Venezuela.

The Shreveport Section of the Southwestern Geological Society took a field trip to trace the Eocene-Cretaceous outcrop, June 9.

Mr. EDWIN B. HOPKINS has just returned from consulting work in Venezuela, South America, and has taken up his duties in his New York office.

In the May-June issue of the *Bulletin* it was erroneously stated that BEN K. STROUD had accepted a position in Los Angeles with the National Supply Company. Mr. Stroud is with the National Tube Company of Pittsburgh, Pa., acting as Field Engineer representing the Manufacturing Department.

KESSACK D. WHITE was married in Buenos Aires on April 18, 1923, to Miss Elsie Bang Gronnegaard.

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